Nottingham University Business School

MSC Dissertation

A research about data-driven simulation approach for Rolls-Royce 150 seater engine supply chain

Masters of Science Operations Mangement

by
Shuaijie Shi
2007

Confidential

Business School, the University of Nottingham

Acknowledgements

I would like to thank following for their enthusiastic support for my dissertation

Dr. James Tannock, my project supervisor, Nottingham University

Jonathan Dadley-Webb, Rolls-Royce plc

Dr Mike Byrne, Nottingham University

and particularly

Dr Bin Cao, Nottingham University

Abstract

This dissertation is about a data-driven simulation applied on the supply chain improvement project for Rolls-Royce. Rolls-Royce is now planning design an engine for 150 seats Boeing 737. One of requirements of Boeing is less than 65 days lead time. Compared current 2 years lead time, it is a big challenge for Rolls-Royce's supply chain. A data-driven simulation method is applied in this article to solve this problem. The model of 150 seater engine supply chain is built by data-driven simulation. Supply chain theories are used to analyze the model and provide solutions. Data-driven simulation experiment one of the solutions in supply chain model. At last, recommendation is given in last chapter.

List of Content

List of Figures

List of Tables

Chapter One: Introduction

1.1 Project requirement

This dissertation is based on the requirement of Rolls-Royce plc. The original requirement is the new market launch plan of Rolls-Royce airplane engine. Currently, Rolls-Royce is planning to design a new engine for 150 seats Boeing 737 airplane, which is the most popular used airplane in the world. In fact, most Boeing 737s are using General Electric and Snecma on the CFM 56 engine, but not Rolls-Royce's product. To compete with General Electric, one of the biggest challenges of Rolls-Royce is lead time. The lead time of engine manufacture is about 2 years now, but the requirement of Boeing is 65 days. Thus, this is also the requirement of this dissertation. Taking out a plan to decrease lead time of 150 seats engine until less than 65 days and experimenting its availabilities with the help of data-driven simulation are the project requirement from Rolls-Royce.

The importance of this project could be understood from the huge market opportunity of Boeing 737. So far, Boeing 737 is the one of most successful airplane in the world. "With over 7,000 ordered and over 5,000 delivered, it is the most ordered and produced commercial passenger jet of all time and has been continuously manufactured by Boeing since 1967. The 737 is now so widely used that at any given time, there are over 1,250 airborne worldwide (Boeing, 2006)."

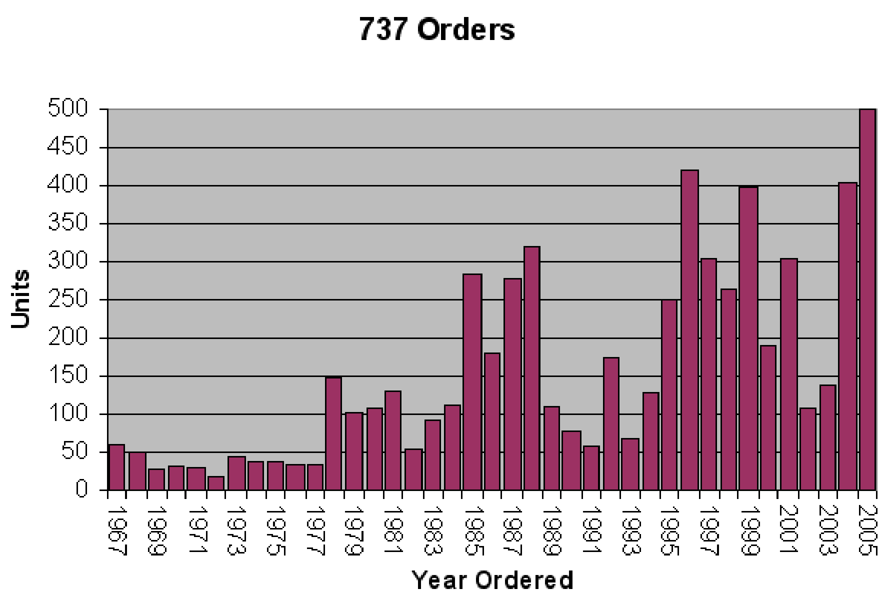


Figure 1.1 Boeing 737 order numbers form 1967 to 2005

Source: Boeing Technical Site

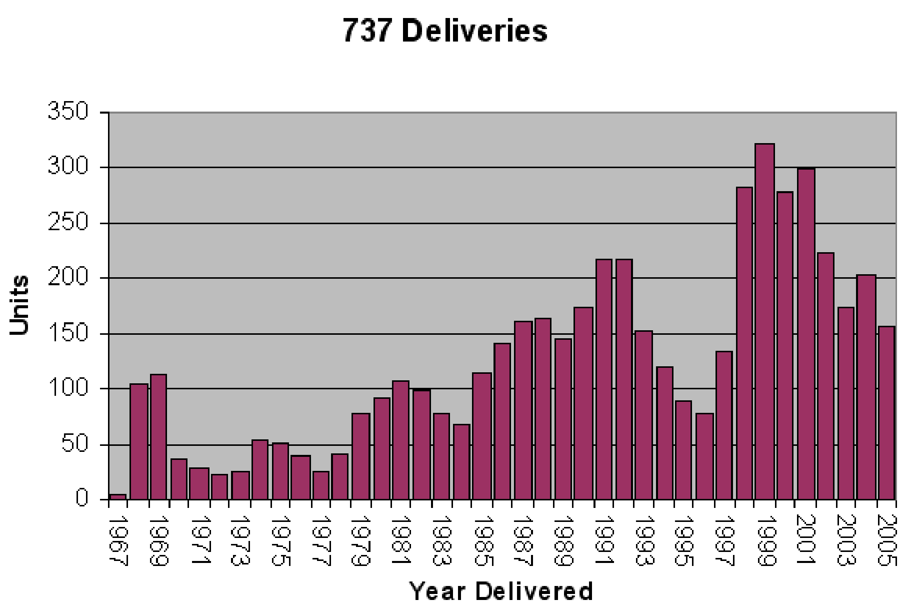


Figure 1.2 Boeing 737 deliveries from 1967 to 2005

Source: Boeing Technical Site

From the Figure 1.1 and Figure 1.2, the demand of Boeing 737 is significant. And the demand is much higher than the delivery rate of Boeing. But, unfortunately, as the second largest engine manufacturer, Rolls-Royce has no product for the most popular airplane in the world. The success in this market could take a considerable benefit for Rolls-Royce engine. As a company that have successful experience on many Boeing engines, such as Boeing 777 (Trent 800) and Boeing 747 (Trent 900), Rolls-Royce should have enough confident either form technology side or supply chain network. The only thing need to do is design an engine which meets the requirements of Boeing 737. One of these requirements is limited order lead time in 65 days. This is also the target of this dissertation.

To achieve a supply chain target for a product which has not been designed, simulation is the only approachable method. Moreover, simulation is also an economy method. By using the existed data in Rolls-Royce database, the simulation could be more reliable. Data-driven simulation is a perfect method to link ERP data in Rolls-Royce to simulation method. In addition, the data-driven simulation could not only provide information of how 150seater engine supply chain will performance, but also doing experiment on its model.

1.2 Aim and objectives

Aim: work out the improvement suggestions for reducing lead time of 150 seater engine with the help of data-driven simulation

Objectives:

- Review the relevant literature about supply chain management and modeling and simulation

- Simulate the supply chain of 150 seat engine by using current Trent 800 04 model
- Understand Trent 800 04 model with the help of data-driven simulation
- Evaluate the current Trent 800 04 model from the lead time performance
- Take out possible solutions of limited lead time in 65 days
- Experiment solutions in data-driven simulation
- Recommend how to improve 150 seater engine

1.3 Dissertation structure

This dissertation has 6 chapters. They are introduction, literature review, methodology, data driven simulation and data collection, supply chain reconstruction planning and simulation experiment, and conclusion.

Chapter one is introduction, which introduce the basic information of dissertation, such as: topic, aim and objectives and background information.

Chapter two is literature review, which involves two parts. Part one states all relevant theories about this research from the supply chain management view. Part two introduces the simulation sight of this dissertation, from basic idea of simulation to the specific supply chain data-driven simulation.

Chapter three is methodology. The research method of 150 seats supply chain improving program will be planed in this chapter, which includes: research design, research process, data collection and the applicability of possible solution.

Chapter four and chapter five is the most important part of this dissertation, in other words they are the main body. Chapter four will concentrate on the theoretical approach of lead time decreasing plans, such as the analysis of original supply chain model, discussion of possible solutions and the approach method selection. Chapter five improves the solution of chapter four and put it into simulation experiment. The output result will also be discussed.

Chapter six is conclusion chapter. It will take out the final conclusion and recommendation of this dissertation.

Chapter Two: Literature Review

To achieve the target of reduce leading time of Rolls-Royce 150 seater engine, knowledge from supply chain management and date-driven simulation is relevant. Because of the fact that 150 seater have not been designed yet, all simulations and supply chain literature review are only theoretical assumption based. Even thought the reality of applicable approach also could be practical valued with the help of data driven simulation.

In this chapter, the first part concentrates on the theory of supply chain which related to the reduction of leading time. The application of simulation is discussed as the second part.

2.1 Supply Chain Management

"A supply chain may be defined as an integrated process where in a number of various business entities (i.e., Suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials, (2) convert there raw materials into specified final products, and (3) deliver these final products to retailers." (Beamon, 1998) As is described by Peter Meindl (2004), there are significant connections between supply chain issues and the success of a firm.

Currently, with the rapid development of technology and global commerce, modern business faces a much more various demand. From this point, business competition is not only happened among separated companies, but also involved upstream and down stream companies, and further more, related to different supply chains. As a result, the supply chain management indicates a tangible practice to adapt modern competitions.

2.1.1 Supply chain management definition and background

"The supply chain encompasses all activities associated with the flow and transformation of goods from the raw materials stage (extraction), through to the end user, as well as the associated information flows. Material and information flow both up and down the supply chain…A net work of organizations that are involved, through upstream and downstream linkages, in the processes and activities that produce value in the form of products and services in the hands of the ultimate customer."(Handfield&Nichols, 2002)

This definition was developed by David Simchi-Levi, Philip Kaminsky and Edith Simchi-Levi (2003) in *Managing the Supply Chain: The Definitive Guide for the Business Professional*. "Supply chain management is primarily concerned with the efficient integration of suppliers, factories, warehouses and stores so than merchandise is produced and distributed in the right quantities, to the right locations and at the right time, and so as to minimize total system cost subject to satisfying service requirements." In the other hand, logistical management, as another important definition related the leading time research, could be described:"include the design and administration of systems to control the flow of material, work-in-process, and finished inventory to support business unit strategy."(Bowersox & Closs, 1996)

For the relationship between supply chain management and logistic management, David Frederick Ross (1998) states "…SCM (supply chain management) has been instrumental in merging marketing and manufacturing with distribution functions to provide the enterprise with new sources of competitive strength. In addition, the application of SCM can be seen in the pursuit of shorter cycle time and reduced channel cost." In other words, supply chain management considered much more relevant factors expect logistic management.

Up to 1958, Forrester (1958) has notice the integrated nature among companies inside distribution channel: “management is on the verge of major breakthrough in understanding how industrial company success depends on the interactions between the flows of information, materials, money, manpower, and capital equipment. The way these five flow system interlock to amplify one another and to cause change and fluctuation will form the basis for anticipating the effects of decisions, polices, organizational forms, and investment choices.” He also comes out of the idea using computer to simulate order flow in entire channel system.

In 1985, Dolf Zillmann and Jennings Bryant (1982) have emphasized the weightiness of supply chain: “As in any economic enterprise, the key factor is bottom-line profit for each of the parties along the supply chain.” Even though, the importance of supply chain has not been notice until the booming of global industrialization. A San Francisco-based consulting firm, which is found by Dr. Scott and Dr. Jaffe (1989), expanded it business area to supply chain optimization (Scott & Jaffe, 1989).

The importance of supply chain has not been accepted broadly until its huge success applications such as in Dell and Wall-mart (Harrison, Lee and Neale, 2005). The flourishing of supply chain management applications in modern business should thanks six factors: globalisation, mass customization, core competence and out sourcing, electronic commerce, the Internet and electronic data interchange, and supply chain dynamics and environmental pressure (Whicher, 2007).

A typical supply chain stages includes: Customers, retails, wholesalers/distributors, manufacturers and component/raw material suppliers (Chopra & Meindl, 2004). In 2007, the Supply chain management was defined as "oversight of materials, information, and finances as they move in a process from supplier to manufacturer to wholesaler to retailer to consumer. Supply chain management involves coordinating and integrating these flows both within and among companies. It is said that the ultimate goal of any effective supply chain management system is to reduce inventory (with the assumption that products are available when needed) (Hayden, Wheeler and Schultz, 2007)".

Tage Skjøtt-Larsen and Birgit Dam Jespersen (2005) forward the supply chain management concept to three components: network structure, business processes and management. Their relationships could be shown in figure 2.1.

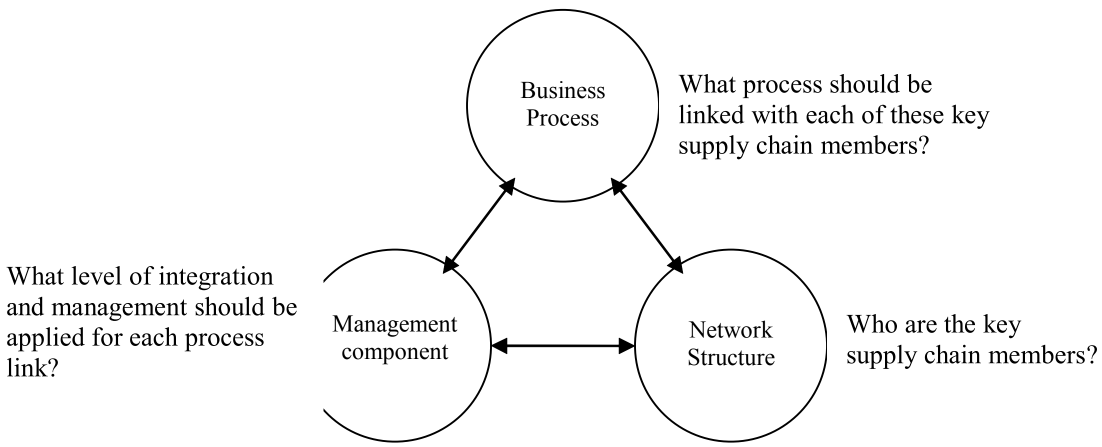


Figure 2.1 Components of the SCM concept
Source: *Supply Chain Management: More than a new name for logistics* (Lamber, Cooper and Pagh, 1998)

2.1.2 Supply chain structures

From the point view of process, there are two basic way to illustrate supply chain: Cycle view and push/pull view. Cycle view divided supply chain into a series of cycles, such as customer cycle, replenishment cycle, manufacture cycle and procurement cycle. The other view, push/pull view defined supply chain into two categories depending on timing of their execution relative to a customer order (Chopra & Meindl, 2004).

Table 2.1 Characteristic of the Push and Pull Portions of Supply Chain

	Push	Pull
Objective	Minimize cost	Maximize service level
Complexity	High	Low
Focus	Resource allocation	Responsiveness
Lead time	Long	Short
Processes	Supply chain planning	Order fulfillment

Source: *Managing the Supply Chain: The Definitive Guide for the Business Professional* (Simchi-Levi & Kaminsky, 2004)

David Simchi-Levi, Philip Kaminsky and Edith Simchi-Levi (2004) developed the pull/push view and forward it into three kind of supply chains: push-based supply chain, pull-based supply chain and push-pull supply chain.

Push-based supply chain are described as "manufacturer bases demand forecasts on orders received from retailer's warehouse (Simchi-Levi & Kaminsky, 2004)". It is "associated with high inventory levels and high manufacturing and high transportation cost, due to the need to respond quickly to demand change. (Lysons & Farrington, 2006) "

"In the pull-based supply chain, production and distribution are demand-driven so that they are coordinated with true customer demand rather than with forecast demand (Simchi-Levi & Kaminsky, 2004)." In other words, real pull-based supply chain does not hold any inventory. As a result, the uncertainty of demand could be ignored and keeping a low inventory level could be possible (Lysons & Farrington, 2006).

The detail information of the strength and weakness between Push-based supply chain and Pull-based supply chain is list in Table 2.1.

Beside these, they also discussed about the reality of push-pull supply chain: “in push-pull supply chain, some stage of the supply chain, typically the initial stages, are operated in a push push-based manner, whereas the remaining stage employ a pull-based strategy(Simchi-Levi & Kaminsky, 2004).”

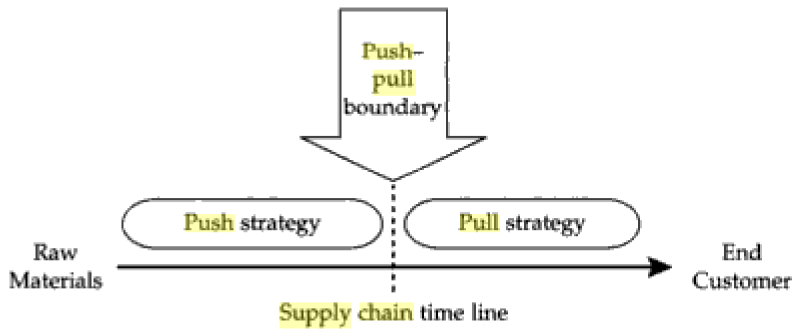


Figure 2.2 Push-pull supply chains

Source: *Managing the Supply Chain: The Definitive Guide for the Business Professional* (Simchi-Levi & Kaminsky, 2004)

Push-pull supply chain mixed the push-based supply chain and pull-based supply chain. At the same time, it inherit the big productivity advantage of push-based supply chain and also benefit the low cost and quickly response from pull-based supply chain. Because of the reality of differences operations process, a buffer inventory is necessary between Push and Pull parts (Harrison & Lee, 2005).

2.1.3 MRP and ERP

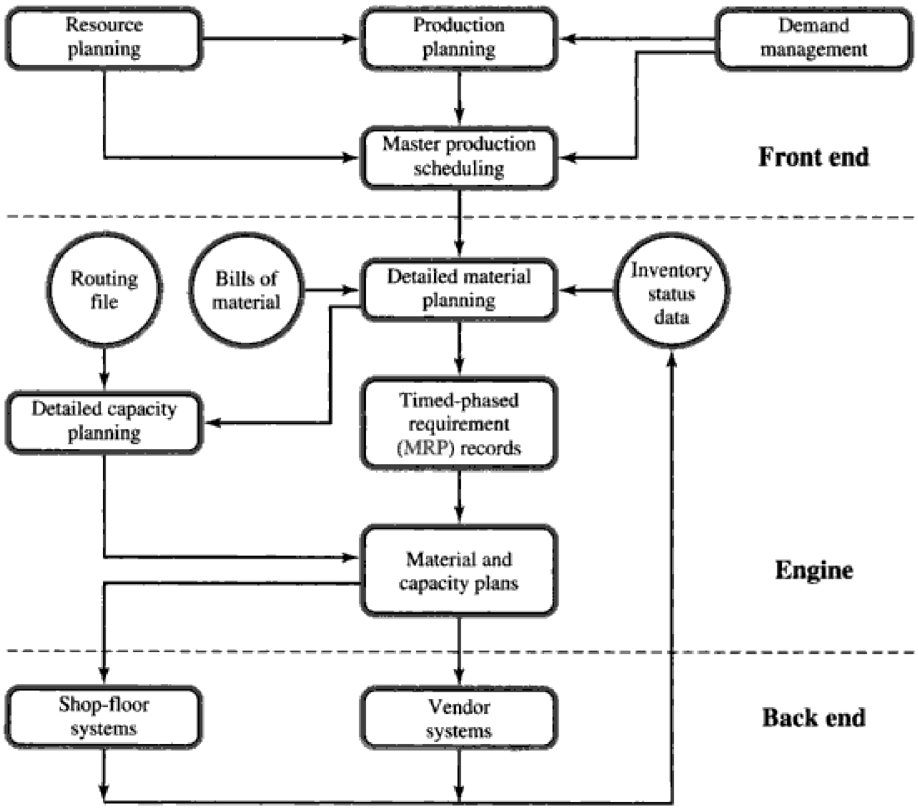


Figure 2.3 An example of Material Requirements Planning (MRP)

Source: *Manufacturing Planning And Control Systems for Supply Chain Management* (Vollmann, 2005)

Beside the pull and push supply chain strategy, MRP (material requirements planning is also popular used as a supply chain strategy. Rolls-Royce's supply chain is also using MRP strategy.

"Material Requirements Planning (MRP) is a software based production planning and inventory control system used to manage manufacturing processes. Although it is not common nowadays, it is possible to conduct MRP by hand as well (Waldner, 1992)."

An MRP system is intended to simultaneously meet 3 objectives (Waldner, 1992):

- Ensure materials and products are available for production and delivery to customers.
- Maintain the lowest possible level of inventory.
- Plan manufacturing activities, delivery schedules and purchasing activities.

In other words, MRP is a very popular form of Push system (Slack & Lewis, 2003). Its philosophy is that materials should be expedited (hurried) when the schedule falls behind and postpones their need (Chase, 2006).

With the development of MRP, ERP (Enterprise Resource Planning) was developed with the popularization of information technology.

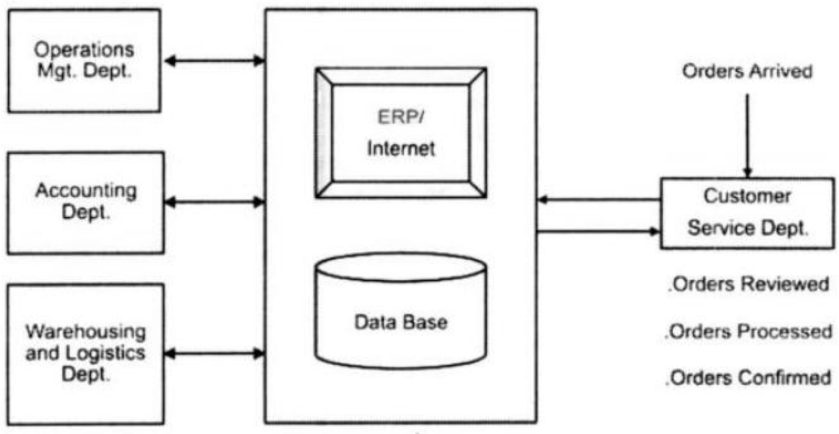


Figure 2.4 A typical ERP customer order processing

Source: ERP and Supply Chain Management (Madu & Kue, 2004)

"ERP is an industry term for the broad set of activities supported by multi-module application software that helps a manufacturer or other business manage the important parts of its business, including product planning, parts purchasing, maintaining inventories, interacting with suppliers, providing customer service, and tracking orders. ERP can also include application modules for the finance and human resources aspects of a business. Typically, an ERP system uses or is integrated with a relational database system. The deployment of an ERP system can involve considerable business process analysis, employee retraining, and new work procedures (Jacques, 2006)." More specifically, ERP is a software control method in operation area.

SAP, which is a company founded in 1972, is the world's largest business software company and the third-largest independent software provider in terms of revenues (Bailor, 2006). Its products focus on ERP, which is also called as SAP ERP system.

In fact, MRP is used as major material and components scheduling method in Roll-Royce in the form of SAP R/3 v 4.7 ERP system (Dadley-Webb, 2007). "R" means real-time, "3" stands for 3 tier client-server architecture (database layer-application layer-presentation layer), which are: database, application server and client (webMethods, 2005).

2.1.4 Inventory theory

"Inventory is the stock of any item or resource used in an organization (Chase, 2006)."

Although most modem operation theories focus on decreasing inventory level to control cost, all companies still keep a supply of inventory. Richard B. Chase, F.Robert Jacobs and Nicholas J. Aquilano (2006) list the reason for holding inventory:

- To maintain independence of operations
- To meet variation in product demand
- To allow flexibility in production scheduling
- To provide a safeguard for variation in raw material delivery time
- To take advantage of economic purchase order size

But holding inventory also cost a lot in forms of holding (or carrying) cost, setup (or production change) cost, ordering costs and shortage costs (Chase, 2006).

2.1.4.1 (R, Q) inventory model

(R, Q) model is also called recorder quantity model. In this model, Q units are ordered when the inventory position reaches level R. The Q units arrive in stock after lead timeτ. The core of (R, Q) model implication is the decision of R and Q. In (R, Q) model, the decision of R and Q could be described by formula (Hahmias, 2005):

$$Q = \sqrt{\frac{2\lambda\{K + Qhn(R)/[(1 - F(R))\lambda]\}}{h}}$$

(λ stands for demand rate, K is fixed set up cost, h is holding cost per unit)

2.1.4.2 (s, S) inventory model

(s, S) is called order up to level model, which order and amount to bring it back to target level S when the inventory position reaches level s. The amount of S and s could be calculated by the formula of (R, Q) through eat s=R and S=R+Q (Hahmias, 2005). Both (s, S) model and (R, Q) model are very similar if s, S, R, Q are fix number. But actually, all of them are also changed in different season and updated rapidly. Compared with (s, S) model, (R, Q) model was found easier to be understood by manager in practise (Kapuscinki, 2004).

2.1.5 Bullwhip effect

In the research of supply chain, there is an important effect which influence supply strategy a lot because the existence of inventory.

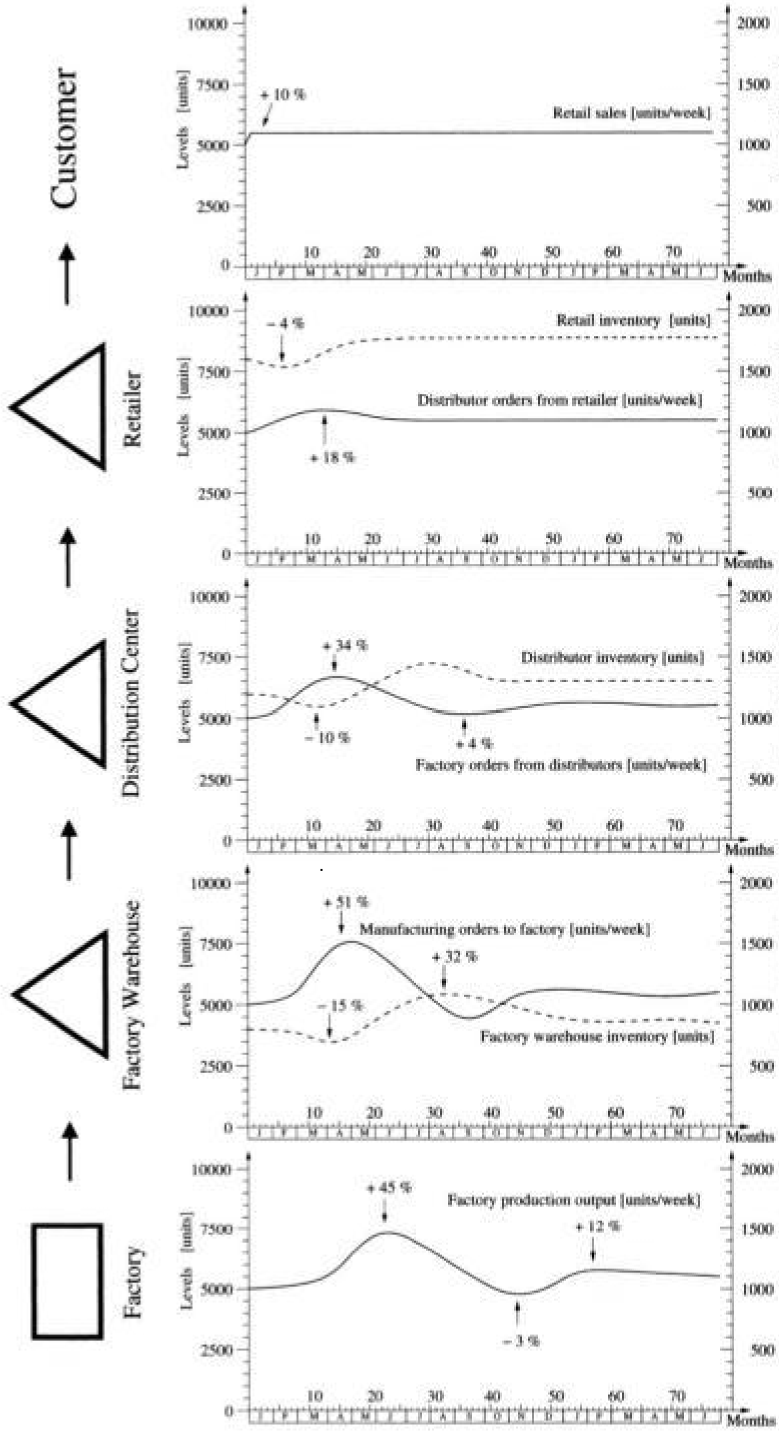


Figure 2.5 Bullwhip effect (along the line of Forrester (1961))

Sourer: *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies* (Stadtler & Kilger, 2005)

"Specifically, the bullwhip effects lead to inefficient resource utilization because planning and managing are much more difficult… in a push-based supply chain, we often find increased transportation costs, high inventory levels, and/or high manufacturing cost due to the need for emergency production changeovers (Simchi-Levi & Kaminsky, 2004)."

The Bullwhip effect is one of most effective element in supply chain performance. All supply chain strategies, include push strategy, pull strategy and MRP, considers it as an important parts. Kenneth Lysons and Brian Farrington (2006) list the most common drivers of bullwhip and it results in *Purchasing and Supply Chain Management*.

The most common drivers:

- Unforecasted sales promotions, which have a ripple effect throughout the supply chain
- Sales incentive plans when extended to, say, three months often result in sales distortion
- Lack of customer confidence in the ability of suppliers to deliver orders on time, leading to overordering
- Cancellation of order, often resulting from previous overordering
- Freight incentive, such as transportation discounts for volume orders, that may cause customers to accumulate orders and then order in bulk.

It is mainly accrue in the forecast-driven supply chain, and for the influence for demand-driven supply chain which reacts to actual customer orders is very little (Lee, Padmanabhan & Whang, 1997). It is also could conduct the result: MRP and Push strategy could be influenced by bullwhip effect and pull strategy could be disturbed little.

2.1.6 Supply chain performance and SCOR (Supply Chain Operations Reference) model

SCOR (Supply Chain Operations Reference) is a cross-industry standard for supply chain management, which is developed by Supply Chain Council (SCC). The SCC, which was established in 1996, is an independent not-for-profit organization (Bolstorff & Rosenbaum, 2003).

SCOR is a very popular supply chain performance tool. It integrated Plan, Source, Make, Deliver, and Return, five distinct management processes (Bolstorff & Rosenbaum, 2003).

- *Plan: Processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production, and delivery requirements.*
- *Source: Processes that procure goods and services to meet planned or actual demand.*
- *Make: Processes that transform product to a finished state to meet planned or actual demand.*
- *Deliver: Processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management.*
- *Return: Processes associated with returning or receiving returned products for any reason. These processes extend into post-delivery customer support.*

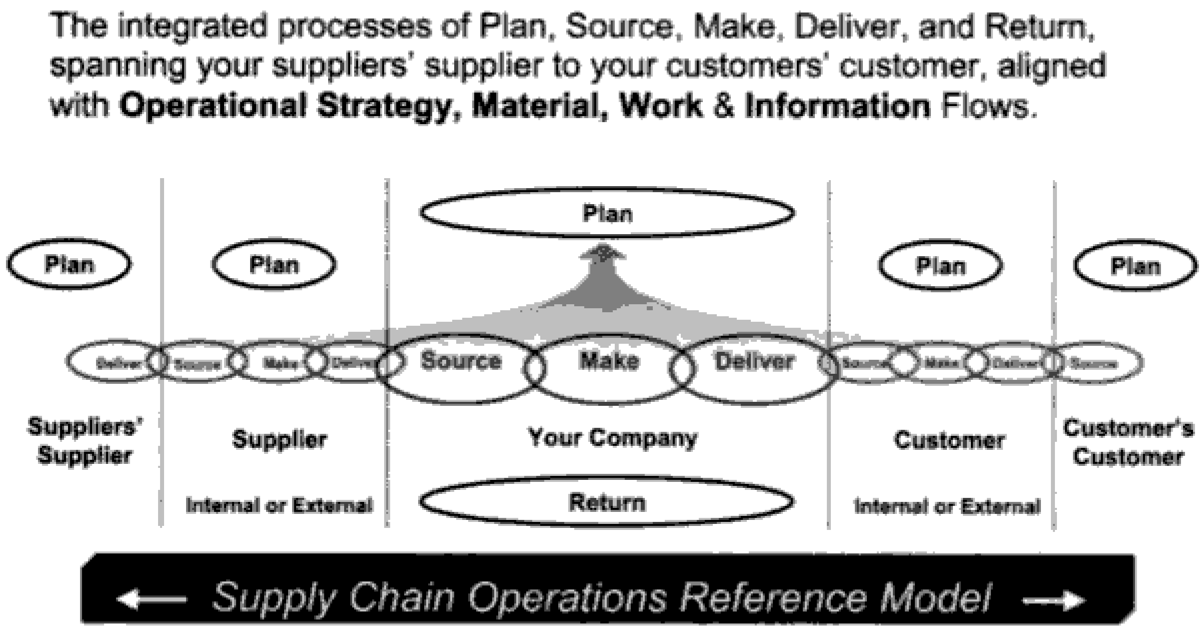


Figure 2.6 SCOR framework

Source: *Supply Chain Excellence: A Handbook for Dramatic Improvement Using the SCOR model* (Bolstorff & Rosenbaum, 2003)

And the performance of the data-driven supply chain model will use this method.

2.2 Date-Driven Simulation

Another important point of this dissertation is data-driven simulation. It is the main method to research the 150 seater engine's supply chain. The following parts will introduce this method specifically.

2.2.1 Simulation

Simulation is first described as:" …for distinction sake, a deceiving by words, is commonly called a lye, and a deceiving by actions, gestures, or behavior, is called simulation…(South, 1697)" It is widely used in many area to stand an imitation of some real thing, circumstance, or process.

The most common method of simulation is using model. Model could be considered as the pattern of real system. In this dissertation, computer simulation is the relevant topic.

Computer simulation could also be called as computer model or a computational model. It is a kind of computer program that attempts to simulate an abstract model of particular system (Hartmann, 1996).It "refers to methods for studying a wide variety of models of realworld systems by numerical evaluation using software designed to imitate the system's operations or characteristics, often over time(Kelton, Sadowski, & Sturrock, 2003)".It is widely used in many areas.

2.2.2 About Data-driven simulation

The idea of data-driven simulation is using the exist database to drive the modeling software so that a model could be driven by the original database. Its benefit could be shown when face large amount of data in simulation. Building model manually is a hard work spends lots of time. At the same time, the simulation driven by database could increase the flexibility of simulation model. When data changed, lots of work could be done automatically without changing data one by one. With the widely application of information technology, it is possible to link model to the database of real system. A data-driven method for simulating clothes worn by 3D characters in real-time , which is created by Frederic Cordier and Nadia Magnenat-Thalmann (2004), has extended the development of data-driven in engineering sector. In data-driven simulations, "the predictions of the simulation are continually adjusted by absorption of new data. The underlying model on which the simulation is based may be revised as a result of data assimilation. It is also possible that the states predicted by the simulation should play a role in selecting the data to be absorbed. If such interactions between simulation and reality are to be automated, they will require intelligent software to manage them (Kennedy & Theodoropoulos, 2005)", this technology approach could be described as data-driven simulation. It emphasizes the development of models which are depend on data maintained and understood by the user department (Franz, 1989).

2.2.3 Data-driven simulation in the supply chain

From the operation views, simulation is recognized as an important tool in the supply chain research. The data-driven simulation of this dissertation is structured as Figure 2.6 shown.

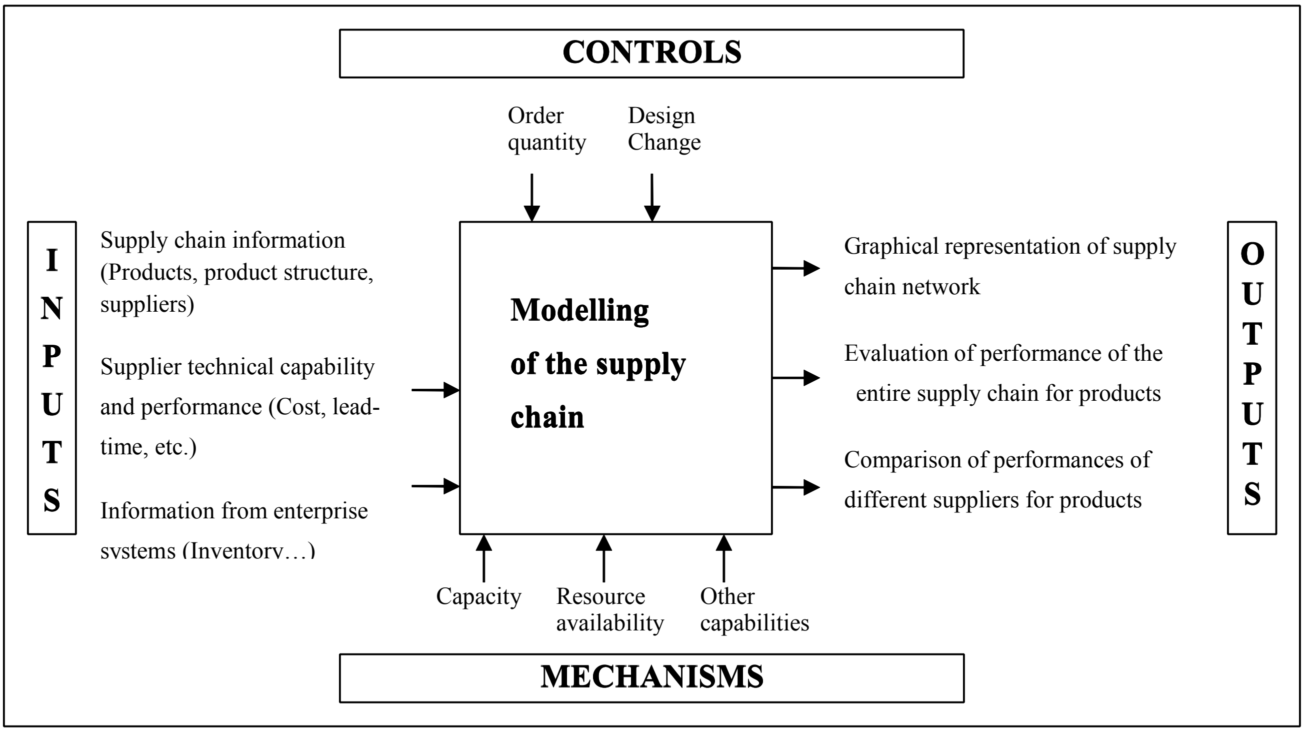


Figure 2.7 Structure of the supply chain modeling system

Source: Modeling the supply chain (Tannock, 2003)

Modeling of the supply chain is the core of the whole system. Around it, inputs, outputs, control and mechanisms are four types of arrows. Supply chain information, supplier technical capability and performance, information from enterprise are main inputs of system. Order quantity and design change are provided as control parts from the sight of the whole supply chain. All inputs need to through the mechanisms process, which includes capacity, resource availability and other capabilities, to arrived output at last. Graphical representation of supply chain network, evaluation of performance of the entire supply chain for products, comparison of performances of different suppliers for products are conducted as output (Tannock, 2003).

In modeling the supply chain (Tannock, 2003) is also prescribe as described blew:

Modeling Assumptions:

- The supply chain modeling task is undertaken from the viewpoint of a systems integrator or prime contractor. The model shows the upstream supply chain for a complete product, or a part of a product (i.e. an assembly).
- Supplier companies within the extended enterprise provide the data necessary for capability assessment and supply chain performance evaluation. (In the VIVACE concept, data concerning each supplier will be obtained from the Extended Enterprise Collaboration Hub facility to be developed by WP 3.6).
- All the companies use the same codes and names, etc., for the same product.
- Supplier companies do not hold any stock. (The modeling functionality could be extended to take account of stock by adding this information or integrating with company ERP/SCM systems.)
- Transportation lead-time and associated cost for each product are constant. (The transport lead-time and cost functionality could be extended, to be determined by

a combination of the location of customers, transportation mode and other product characteristics such as size and weight.)

- Lead-time for the product ordered depends on batch order quantity. For example, if order quantity is 10, lead time for orders which require ≤10 quantity of the product is the same.

Data requirements of the model. Based on the objectives and scope of modelling, the necessary data must be defined to implement the model by using a database system. The requirements can be summarised in three categories.

- Basic data: product and supplier information will be needed. Product data is based on the Bill of Materials (BOM) parts explosion. It should include type of product, for each product, to integrate the product into supply chain.
- Supply chain data: supply chain data should be able to represent product structure as well as supply chain information in terms of supplier(s) which provide (or can provide) each item in the product hierarchy. In addition, the data should be able to accommodate product optional configurations and alternate suppliers, in order to increase flexibility for modelling possible supply chains.
- Supplier performance data: key metrics to measure supplier performance. In particular, information on cost and lead-time are important, and other performance metrics (e.g. quality, delivery reliability) should also be provided. Order quantity may have a significant impact on the delivery performance of a supplier, so that differential time and cost information based on order quantity should be available.

2.2.4 Supply Chain Model Builder

Supply Chain Model Builder (SCMB) is the most important tool in this dissertation. It is established on the research of supply chain data-driven simulation. More accurately, it is the physical approach of supply chain data-driven simulation. The latest version of SCMB is ver.1.7.5.1. The running of this model needs the corresponding Microsoft Assess database support. The detail of SCMB will be discussed below:

- About the basic structure of SCMB

The SCMB is built on the base of Supply chain database, but it is not all the elements of supply chain model build. Indeed, supply chain model build is a translator who translates information from the supply chain database and expressed it in Arena Simulation.

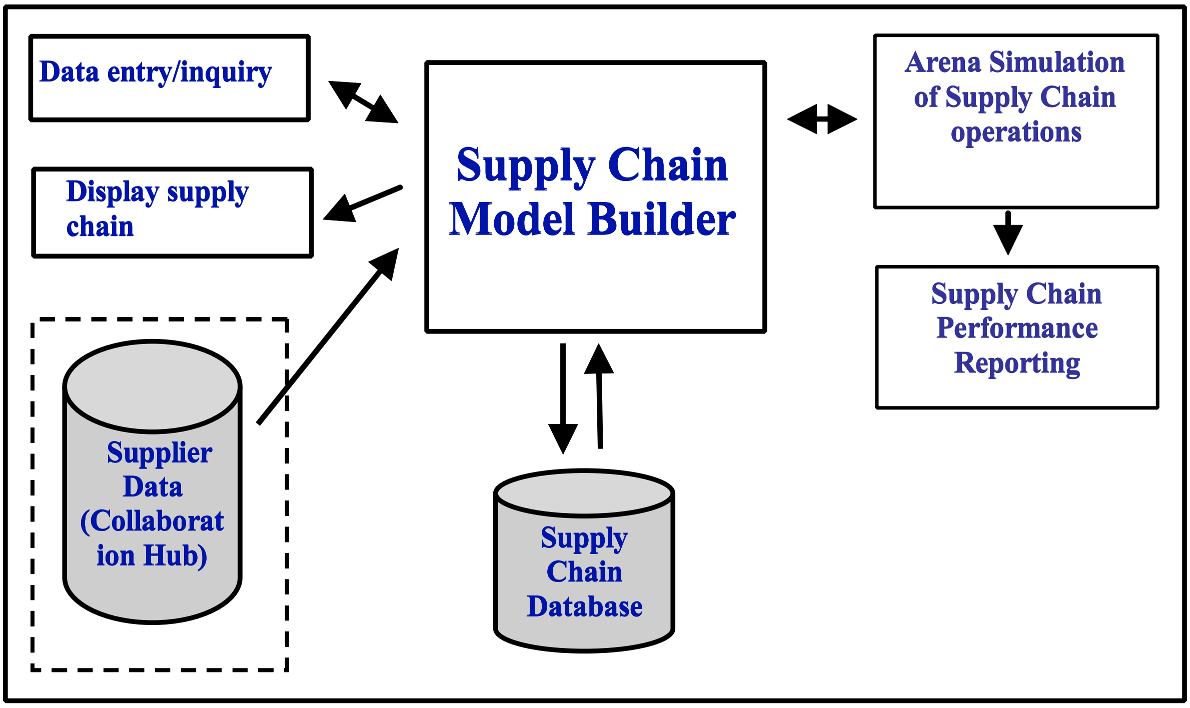


Figure 2.8 SCMB structure

Source: *Supply Chain Model Builder User Manual* (Cao, 2005)

Figure 2.8 is the SCMB structure. The upper square in the middle of this figure is the user interface of the SCMB; the column blow is the associate Access database. Through the data entry, SCMB could display the supply chain. When doing simulation, SCMB could represent an internal database for supply chain model. And an arena simulation of supply chain operations could be build. A supply chain performance report could output by running the arena model.

- About the database structure of SCMB

To build a model by SCMB, database with necessary information about supply chain is demanded. The database document which is provided is an Excel document. Using the already existed program inside, an accessed document could be provided. There are 17 tables in this document, which are application_options, demand, inventory_parameter, order_process_time, planning_and_delivery_window, product, product_option, product_option_desc, product_supply_chain, production_schedule, rpt_performance, rpt_supply_chain, schema_field_layout, supplier, supplier_performance, supplier_performance_by_qty and transport. In these tables, all information of Trent 800 04 model has been provided, as the requirement of SCMB.

Figure 2.9 and figure 2.10 are the relationship between different tables in database documents.

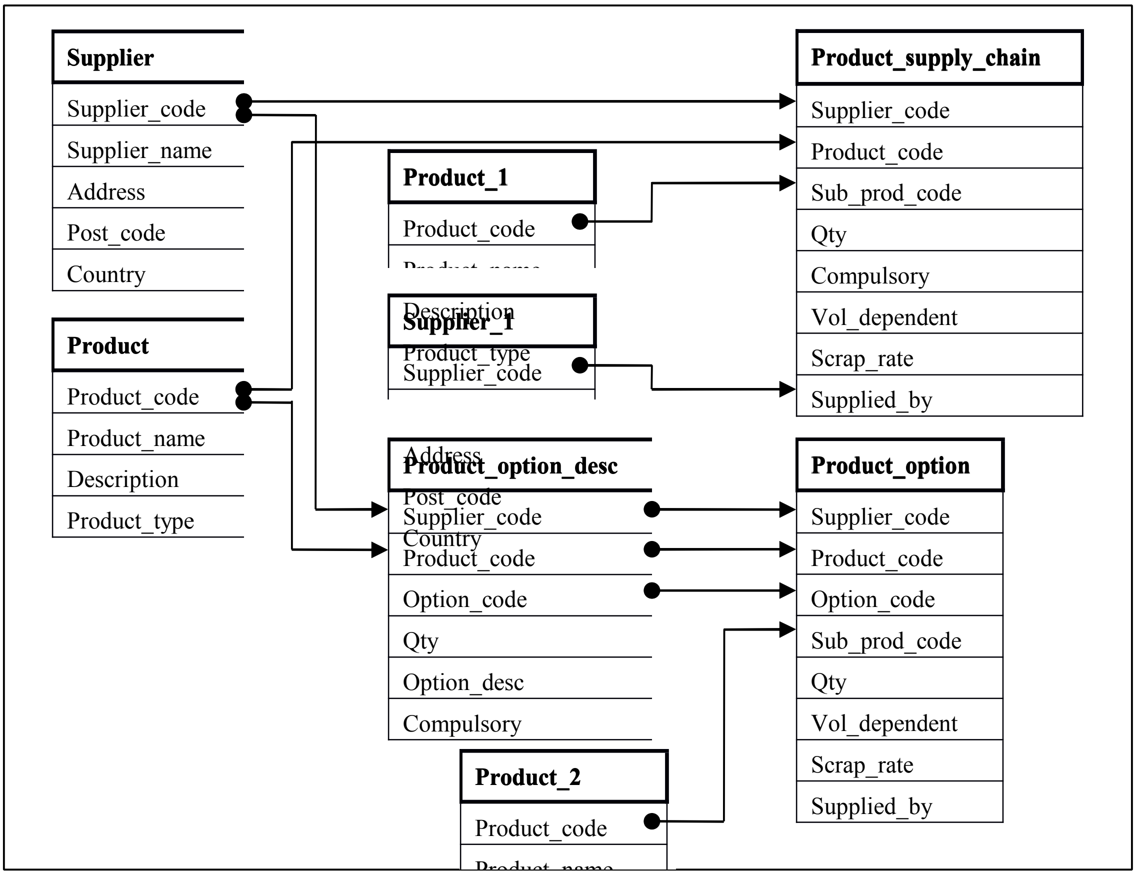


Figure 2.9 Relationship relevant to supply chain table

Source: *Supply Chain Model Builder User Manual* (Cao, 2005)

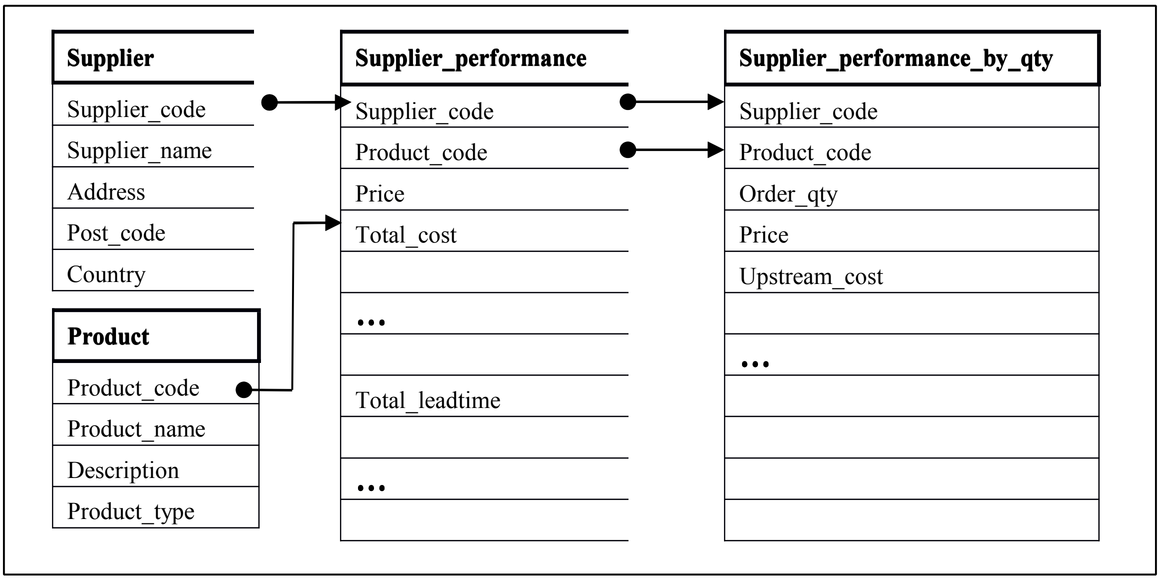


Figure 2.10 Relationship relevant to supply performance table

Business School, the University of Nottingham

Source: *Supply Chain Model Builder User Manual* (Cao, 2005)

The SCMB uses the technique of multiple document interfaces (MDI) in order to display several different representations of the supply chain. Each document represents a form of the supply chain, which has a tree view on the left showing hierarchical structure of the supply chain, and two list views on the right showing product supply chain and performance information, for the product or supplier selected on the tree view (Cao, 2005).

2.2.5 Other relevant information

- The simulation running environment
    - Hardware Platform

      All programs, including Rockwell Arena and SCMB, and the database are run at the IBM T42 2373K5H laptop computer, the detail of hard hardware information is listed:

      CPU: Inter Pentium M Dothan Processor 1.7 G

      Memory: 1.5 G

      Hard disk 120 G

    - Software Platform:

Windows XP professional Version 2002 Service Pack 2

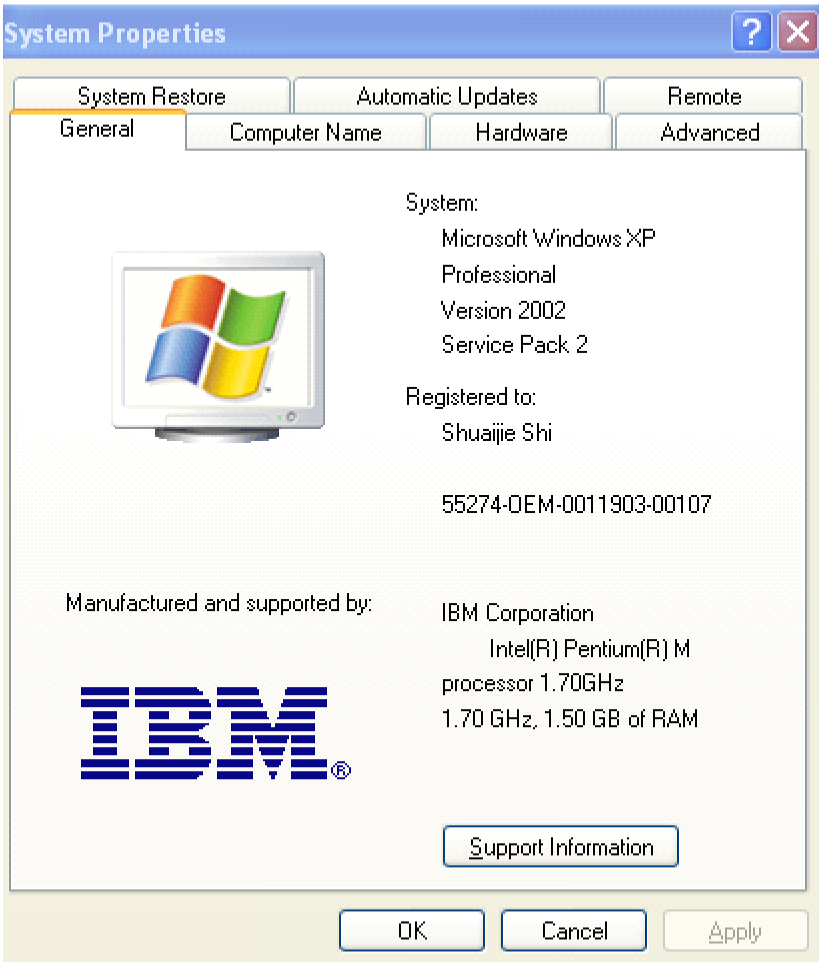


Figure 2.11 Hardware and Software platform

- Other software information

The Rockwell Arena is a true Microsoft® Windows® operating system application. It is powerful simulation software. The Arena used in this dissertation is version 8.01.00. The use license is authorized by Rolls-Royce.

The Supply chain model builder is also authorized by Rolls-Royce, and the version is 1.7.5.1. To help the research in this dissertation, Dr Bing Cao has improved it with adding MRP+ Finish product inventory model in it.

Chapter Three: Methodology

3.1 Research Design

To solve the lead time problem of Rolls-Royce 150 seater engine, a research design is necessary to take out at first. Through the project requirement and the scope of dissertation topic, data-driven simulation is the major research tool in all research process. It comes with the whole process of this dissertation.

In the other side, the major aim of this project is to improve supply chain in order to achieve market performance of Roll-Royce. The data-driven simulation is operated before any physical executive of real 150 seater engine. Currently, the data-driven of Trent 800 04 model runs almost the same as the real situation. This proved that the data-driven simulation is a efficiency research tool of current supply chain, and any improvement of this supply chain has practical meaning in the future. In other words, it is the basic of all research.

In summary, the target of research is to improve the supply chain of 150 seater engine and the major method is data-driven simulation. Once understanding these two points, the research design could be tangible.

3.1.1 Principals of research design

First of all, the data-driven simulation is a quantitative research method.

At the first glance, the basic method of research could classified by quantitative research and qualitative research (Remenyi, 1998). Quantitative research is typically taken to be exemplified by social survey and by exemplified observation. Qualitative research tends to associated participant observation and unstructured, in-depth interview (Bryman, 1988). The implementation of these two methods will decide the way and the result of research.

And as is described at beginning of this chapter, the method of this dissertation is data-driven simulation. From the sight of database dependability, the mathematic approach in the simulation process and the numerical result of simulation experiment, data-driven simulation itself, with out any doubt, is the quantitative research method.

Secondly, in what extent, the result of data-driven simulation will be suitable to guide real operation of 150 seater engine. So far, there is no any data about 150 seater engine. All the simulation data are from Trent 800 04 model. And an important point is, in this dissertation, the Trent 800 04 model is hypothesized to be the 150 seater Boeing 737 engine. Another question about the similarities between Trent 800 04 model and 150 seater engine is significant related to the reliability of research result.

For the applicability of the data-driven simulation for 150 seater engine supply chain, the data-driven simulation has a lot of successful experience in many products, especially, these included the Trent 900 and Trent 800 of Rolls-Royce. The practice of these simulation experiences proved the readability of data-driven simulation in supply chain from the practical view. In addition, the data-driven simulation is designed for Trent 800 is based on the research of its supply chain process and almost all data are from the Rolls-Royce database. The input and the process of this methods are creditable, moreover, the outputs (results) have been inspected the same as practice.

The other thing need to be mentioned the about Trent 800 04 model and 150 seater engine supply chain. Above all, this research is about the supply chain which involved many manufacture company, not only Roll-Royce. Judging from the similarity of supply chain, even the 150 seater has not been designed yet, the supplier and customer network could not have too much different. So the performance of supply chain network will be similar in most area. At the same time, Trent 800 is the engine for Boeing 777 and the 150 seater engine will be for Boeing 737. Although the Boeing 777, which can take over 300 people, is much bigger airplane than Boeing 737, as engines for same series, 150 seater engine supply chain could be researched from the similar base.

Finally, because all information of 150 seater engine are based on the simulation of Trent 800, and how these result could be applied on future 150 seater engine supply is a serious problem. The discussion about this part will be illustrated in 3.4.

In summary, the research about 150 seater engine supply chain is executive by quantitative research method. More specifically, the Trent 800 04 model data-driven simulation will be used as the example of 150 seater engine. After that, the discussion about similarity and distinctness are necessary added at the complementarily of research.

3.1.2 Research process

As is shown on Figure 3.1, the research process has five steps in this dissertation. They are: Establishing the M4800T004_71999 model by data-driven simulations, analyzing the supply chain of M4800T004_71999, taking out possible solutions and discussing theoretically, selecting one of the best solutions and putting into data-driven simulation experiment, and discussing the result and give recommendations.

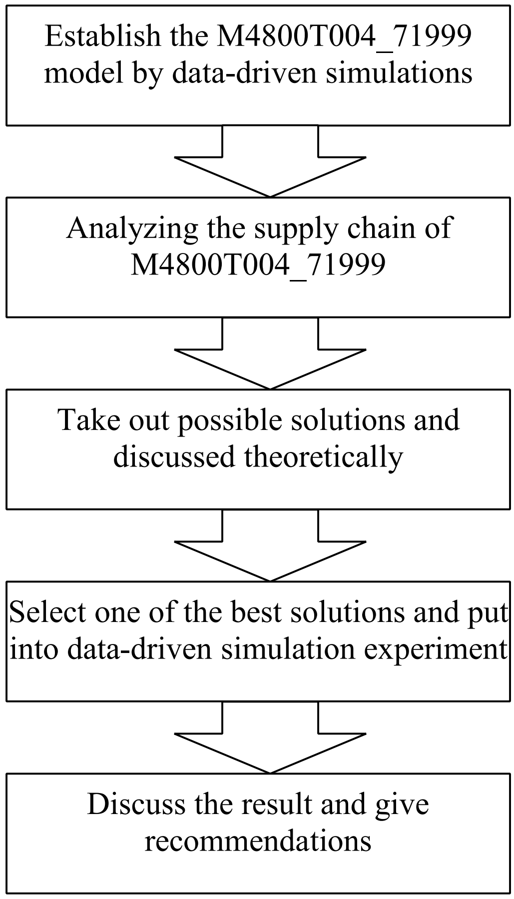


Figure 3.1 Research Process

- Establishing the M4800T004_71999 model by data-driven simulations

In this step, a model of M4800T004_71999 (Trent 800 04 model) is established base on the already existed M4800T004_71999 database by SCMB. Following the instruction of SCMB requirement, an Arena simulation model will be established. Through running this model, the output data could be collected.

- Analyzing the supply chain of M4800T004_71999

After the collection of supply chain output, the M4800T004_71999 supply chain will be much clear to be analyzed. For the lead time view, the queue time in every process, the order fill rate and cost could be noticed in the simulation model. Using the knowledge of supply chain management, its situation could be researched by specific methods.

- Take out possible solutions and discussed theoretically

The understanding of supply chain situation gives adequate proof to take out solution method of current supply chain. After that, it is possible to evaluate every solution by supply chain theories. The evaluation could come out a better solution to be experiment by data-driven simulation.

- Select one of the best solutions and put into data-driven simulation experiment

In this step, the most important thing is to check the tangibility of solution which has been chosen in last step. The output will be collected, especially, the lead time will be researched to check whether it accord requirement.

- Discuss the result and give recommendations

Finally, the result will be discussed, such as the cost, throughput, order full fill rate and so on. The final recommendation will be listed at last.

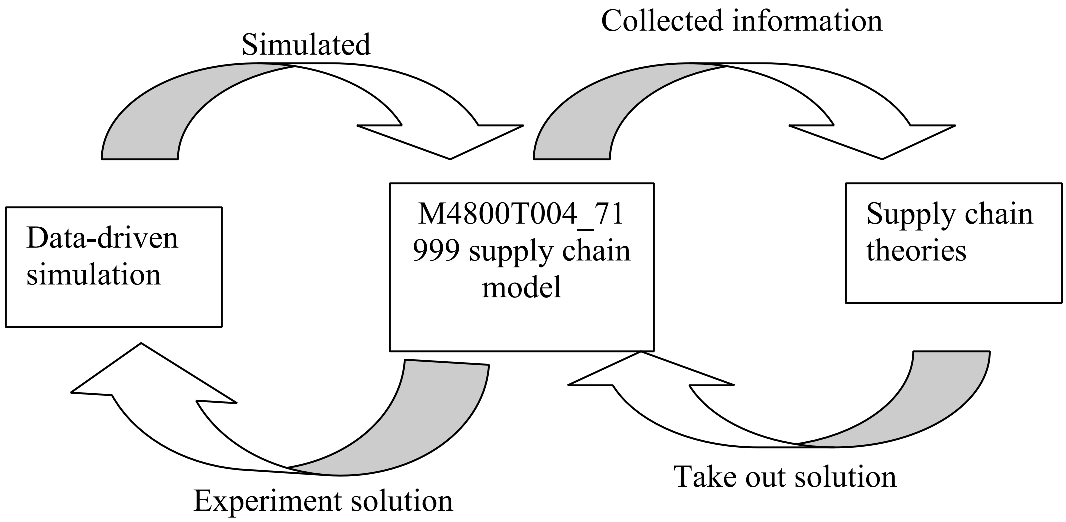


Figure 3.2 Relationship of data-driven simulation and supply chain theories

3.2 Data Collection

The data collection is the job which cost a lot time and energy because some information disperses a lot. In this dissertation, the purpose of data collect is to serve the lead time research. To achieve this target, all data relevant to lead time should be particular emphasized. Other data from supply chain is also useful for supply chain model.

3.2.1 Data Requirement of supply chain model builder (SCMB)

To simulate supply chain, the database of supply chain should be complete in order to build a correct model. The information includes:

- Product lists, specifications, bill of materials

The product lists should include the products in the supply chain. The product code needs to be exclusive. The bill of materials (BOM) is very important data. It is used to represent a product structure in MRP/ERP systems. It provides a breakdown of product, assemblies, sub-assemblies, components, materials, etc., and represents the relationships between higher-level parts and lower-level parts. This product structure model is associated with the required quantity and a (usually estimated) scrap rate (Cao, 2005).

- Supplier lists, capacities, capabilities (e.g. reliability, availability), production rates, unit costs, inventory levels
- Distribution capacities, capabilities, lead times and unit costs
- Demand scenarios, customer orders, product prices
- Other supply chain parameters, e.g. inventory parameters
- Other constraints

In summary, for the simulation model of 150 seater engine, all these data are using data of Trent 800 04 model (M4800T004_71999).

3.2.2 The additional data information

In the database, not every data is from the real situation. To those data, which is difficult to get the real data from Rolls-Royce, an appropriate is acceptable in a reasonable bound. Correspondingly, there are some data not very important, could be ignored in the system or might be add in the future with only a little redressal. Those data can leave blank in the database. The system will read them as “0” in the simulation, such as the transport information and order process time.

3.3 The applicability of possible solution

Another thing need to be notice is the demand database. Because the real target of this simulation is about 150 seater engine for Boeing 737, but there is no any data since it has not been designed yet. Even the supply chain of Trent 800 could represent most of its features. The demand of Trent 800 could not be used for it directly. In this research, the volume of demand is imagined as 2 units per week. In the application of solution, it could be bigger, smaller or fluctuated. This situation will be discussed specifically in Chapter five.

Chapter Four: Data driven simulation and data collection

This chapter and Chapter five are the most important part in dissertation. The main research process, logical analysis and reasonable conclusion will be expanded detailed. This chapter focuses on the original data of M4800T004_71999 (Trent 800 04 model), and illustrates some possible solution to improve it.

4.1 Original supply chain simulation

The fist step is collecting data from original model of Trent 800 04 model, which is from Rolls-Royce database. Because of the final target of dissertation is for the 150 seater engine supply chain, whose demand data could not predicted, not for the Trent 800 04 model, so the demand of this supply chain is assumed. Provisionally, it is set as 2 per week. The other possibility of demand will be discussed later. Other data are directly from the Rolls-Royce database. With the help of these data and SCMB, all necessary elements of building supply chain have been collected.

4.1.1 Background of Rolls-Royce and 150 seats engine project

Rolls-Royce plc is a British aircraft engine maker, which is also the second-largest in the world. Its competitor, General Electric Aviation, is the biggest aircraft engine maker in the world (Pugh, 2002). So far, the most popular airplane in the world, Boeing 737 is using General Electric and Snecma on the CFM 56 engine, not the Rolls-Royce's engine. Without any question, to get involve the Boeing 737 engine market is a big achievement. 150 seats Boeing engine project is one part of this attempting. Whatever, the supply chain performance is one of important parts in this project. Before any essential executive, the data-driven simulation could predict the development of this project and take out suitable suggestions.

- Background of supply chain

To illustrate the relationship between lead time and the 150 seat engine supply chain. An existed engine database, M4800T004_71999, is used as the substitute of 150 seat engine, because 150 seats engine have not been designed yet. And the M4800T004_71999 (Trent 800 04 model), as an existed engine with sufficient data to be simulated, could be a typical model of 150 seats engine. This is not only because there are all engines with similar process, but also the evidence in currant situation that even Trent 900 engine performance similar as well.

Engine Specification

SLS, ISA, flat-rated to 30°C/86°F, 895 to 25°C/77°F

Thrust	74,600lb-95,000lb
Bypass ratio	6.2-5.7
Inlet mass flow	2378-2597lb/sec
Fan diameter	110in
Length	172in
Stages	Fan, 8 IPC, 6 HPC, 1 HPT, 1 IPT, 5 LPT
Certification	January 1995
EIS	April 1996

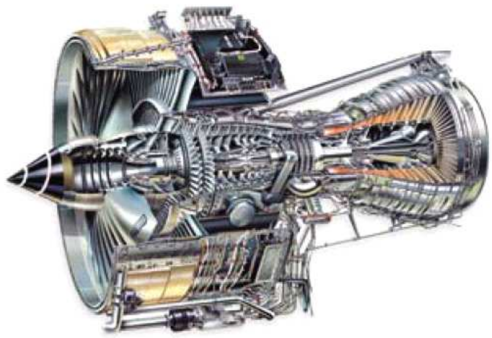


Figure 4.1 Trent 800 engine

Source: *Trent 800: Power for the Boeing 777* (Rolls-Royce plc, 2006)

Trent 800 is the engine manufactured by Rolls-Royce, and is the market lead engine on the Boeing 777. It is a qualitative engine. “Every operator of a Trent 800 is supported by a world-wide network of dedicated local support and the comprehensive

Rolls-Royce services capability. Rolls-Royce is committed to continuous improvement of the Trent 800 family to ensure that the Trent 800 continues to deliver world-class operational excellence.” (Rolls-Royce plc, 2006).

The research of Trent 800 could be used as example of 150 seats engine in the future. The result of M4800T004_71999 supply chain could show the possibility to run 150 seats engine supply chain in many ways to solve the lead time problem.

- About M4800T004_71999 supply chain

The supply chain of M4800T004_71999 is typically two tie supply chain. This is decided by the product structure. M4800T004_71999 is made up of eight components and each component has sub-components. As a result, the supply chain of M4800T004_71999 is two tie supply chain as this components structure,

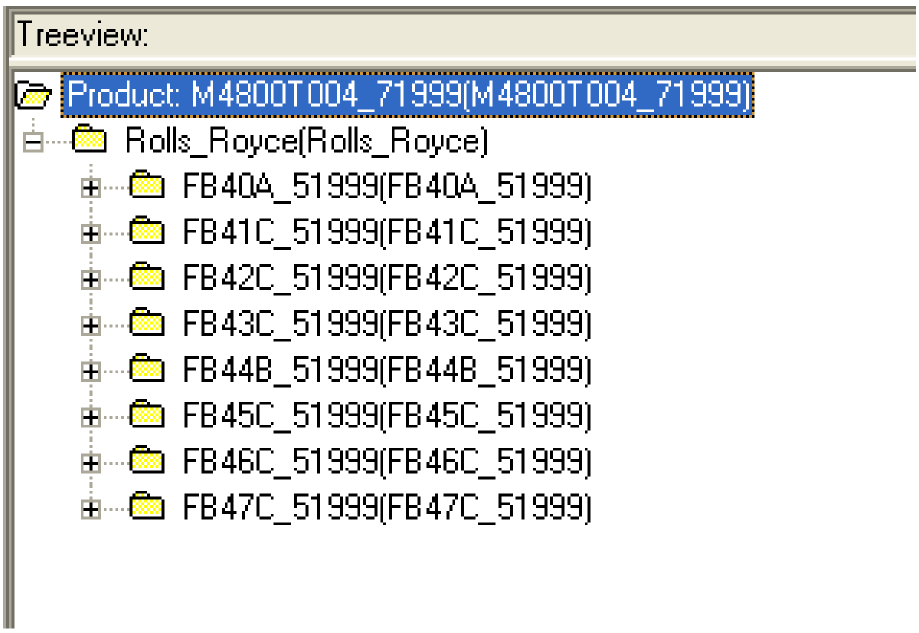


Figure 4.2 The supply chain of M4800T004_71999

Source: Supply chain model builder vision 1.7.5.1

- **Supply Chain network**

Product name: M4800T004_71999

Major suppliers:

SWAGELOK_LIMITED

M_J_SETIONS_LED

A_POOLE_SON_LTD

FARSOUND_ENGINEERING_LTD

CLAMONTA_LIMTED

WETON_EU_LTD

BULWEL_PRECISION_ENGINEERS_LTD

SPS_AEROSTRUTURES_LIMITED

THERMAL_ENGINEERING_PLC

WALTER_ENGINS_A_S

COMMATECH_HOLDINGS_LTD

CHINA_NATIONAL_AERO_TECHNOLOGY

HAYNES_INTERNATIONAL_LIMITED

CHINA_AVIATION_SUPPLIES_IMPORT

JEAN_GALLAY_S_A

SILCOMS_LTD

DONCASTERS_STRUCTURES_LTD

AVIALEC_LTD

PARGLAS_LTD

THOMOSON_MACHINE_TOOL_CO_LTD

Business School, the University of Nottingham

ACCROFAB_LTD

NICHOLSON_SEALING_TECHNOL

OGIES_LTD

BELDAM_CROSSLEY_LIMITED

JAMO_PRECISION_COMPONENTS

_BV

A_O_HENTON_ENGINEERING_CO

_LTD

SPS_TECHNOLOGIES_LTD

ROLLS_ROYCE

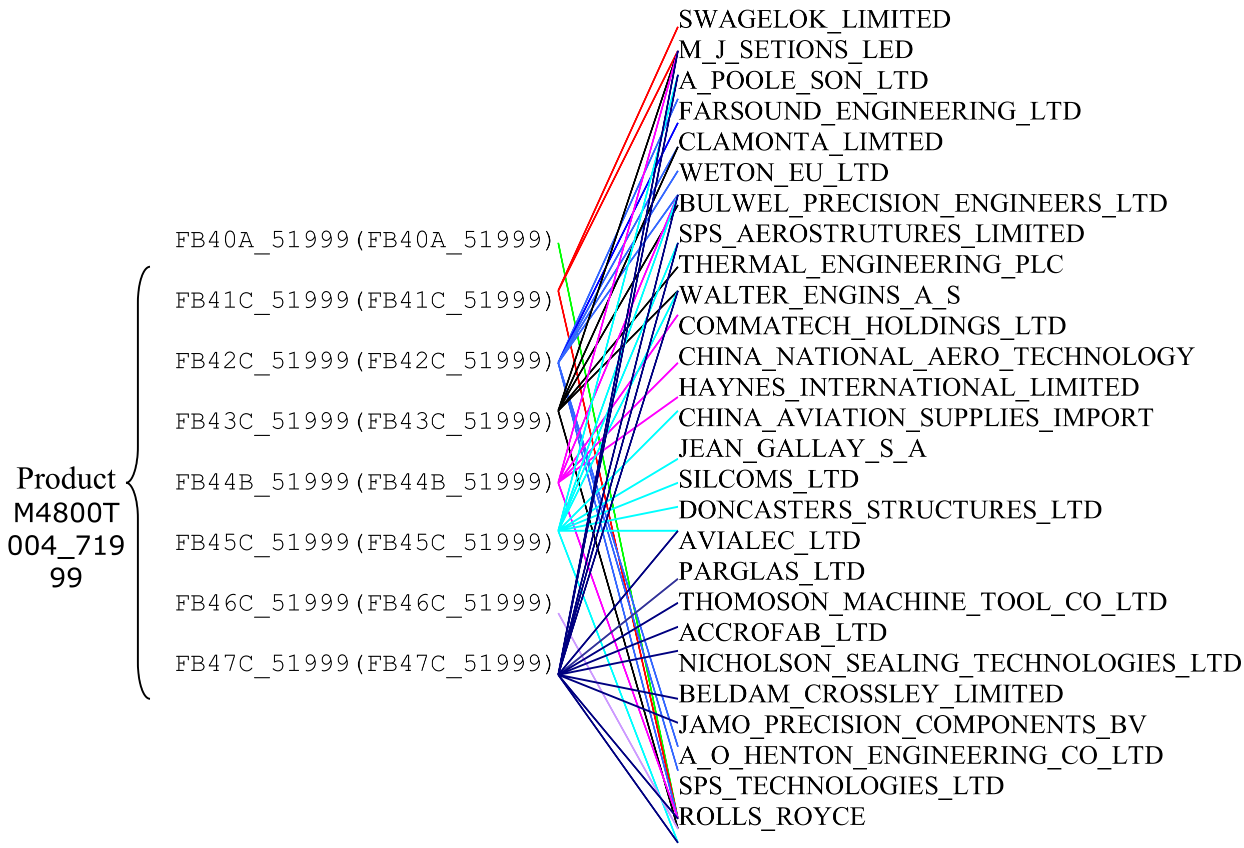


Figure 4.3 The product-supplier relationship network

From figure 4.3, the supplier relationship of eight component in Trent 800 04 model could be described below:

- FB40A_51999 (FB40A_51999) needs 2 components which are all from Rolls-Royce (Internal component).
- FB41C_51999 (FB41C_51999) needs 4 components, 2 of them from Rolls-Royce, one from Swagelok and one form M.J.Section.
- FB42C_51999 (FB42C_51999) needs 17 components, from 8 companies (include Rolls-Royce itself).
- FB43C_51999 (FB43C_51999) needs 19 components, from 6 companies (11 form Thermal).

- FB44B_51999 (FB44B_51999) needs 13 components, from 6 companies.
- FB45C_51999 (FB45C_51999) needs 15 components, from 10 companies.
- FB46C_51999 (FB46C_51999) needs 2 components which are all from Rolls-Royce (Internal component).
- FB47C_51999 (FB47C_51999) 62 components, form 13 companies.
- For product M4800T004_71999, there are 8 components, 134 sub components from 27 companies, and assemble in Rolls-Royce.

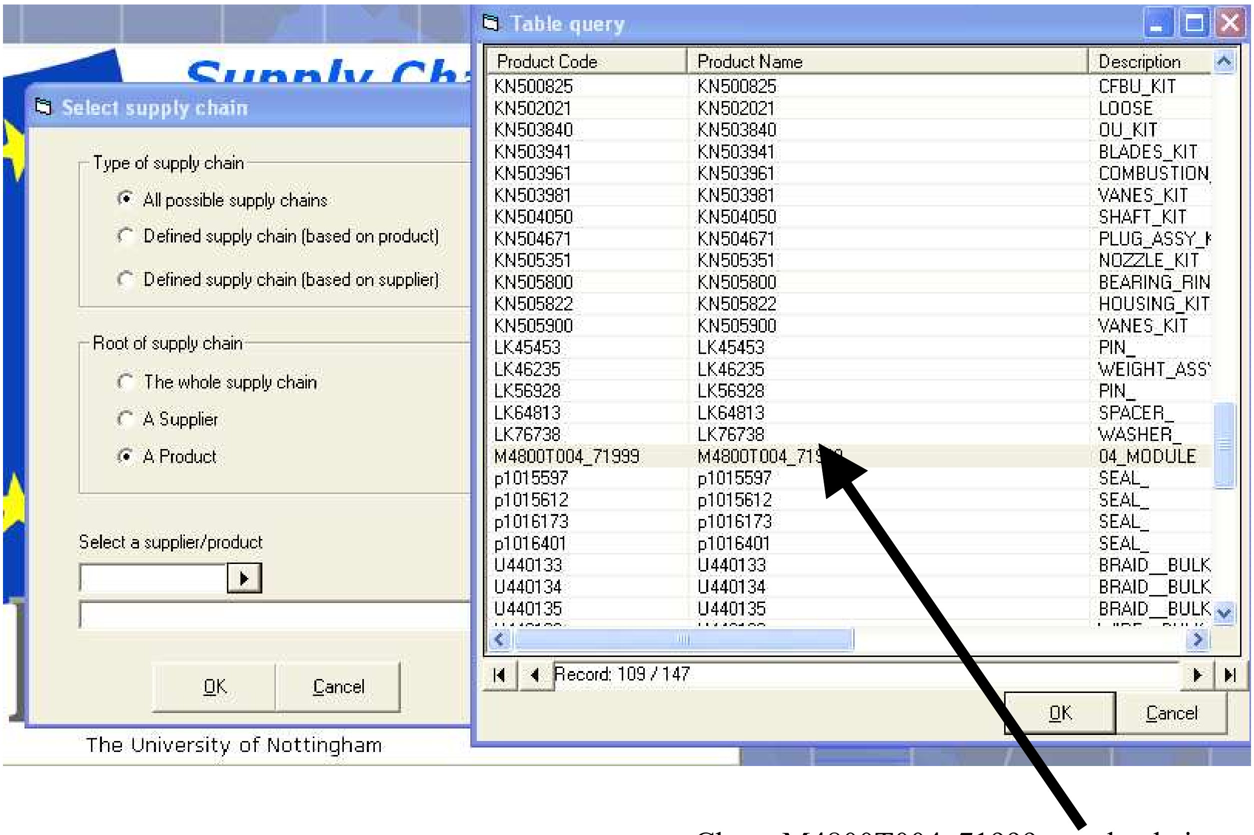
In summary, finish product is M4800T004_71999, and eight components, FB40A_51999, FB41C_51999, FB42C_51999, FB43C_51999, FB44B_51999, FB45C_51999, FB46C_51999, and FB47C_51999 are belong tie one in the whole supply chain. Other sub-components are tie two. It is remarkable that all eight components has Rolls-Royce parts and will be finished in Rolls-Royce at last. And the final assemble line of M4800T004_71999 is also inside of Rolls-Royce.

4.1.2 MRP model of supply chain simulation

- Model building process:

To build the MRP model, firstly, it is important to locate the original Access database in the same folder with SCMB. Next step is running SCMB. Type the document name of database in the database name table. Then it is possible to choose type of supply chain and the boot of supply chain in the user guider. The M4800T004_71999 should be selected as the boot of product in the supply chain as is displayed in Figure 4.1. After the confirmation of input, the structure of database will be on the screen. Figure 4.2 exhibits the structure of M4800T004_71999 in SCMB windows.

Then it is the core of doing simulation for decided the MRP. In the SCMB main window, select the "simulation" menu (as is show in Figure 4.2) and click "do simulation" button. The "do simulation" interface will be on the screen as Figure 4.3 shown. Choose the MRP as inventory model, and leave other option as default value. After this, a Arena model based on the M4800T004_71999 data will be created in Rockwell Arena automatically.



Chose M4800T004_71999 supply chain

Figure 4.4 Product selected interface of SCMB

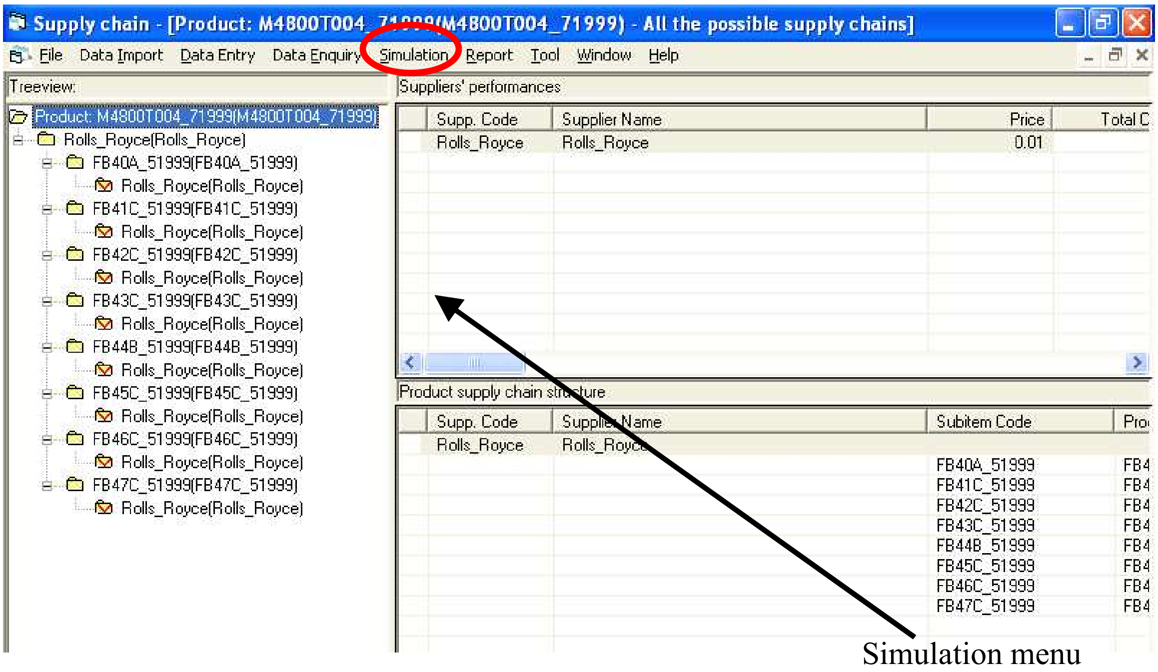


Figure 4.5 The structure of the M4800T004_71999 supply chain in SCMB

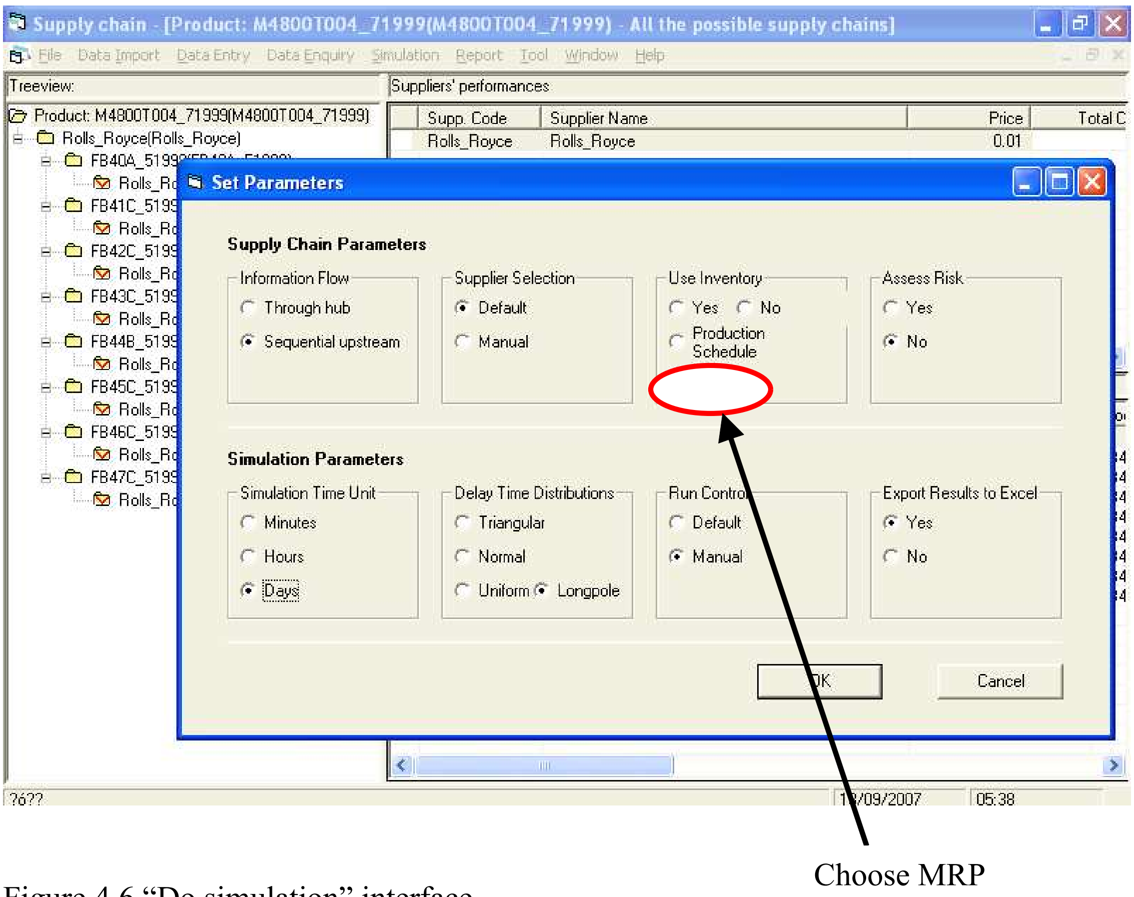


Figure 4.6 “Do simulation” interface

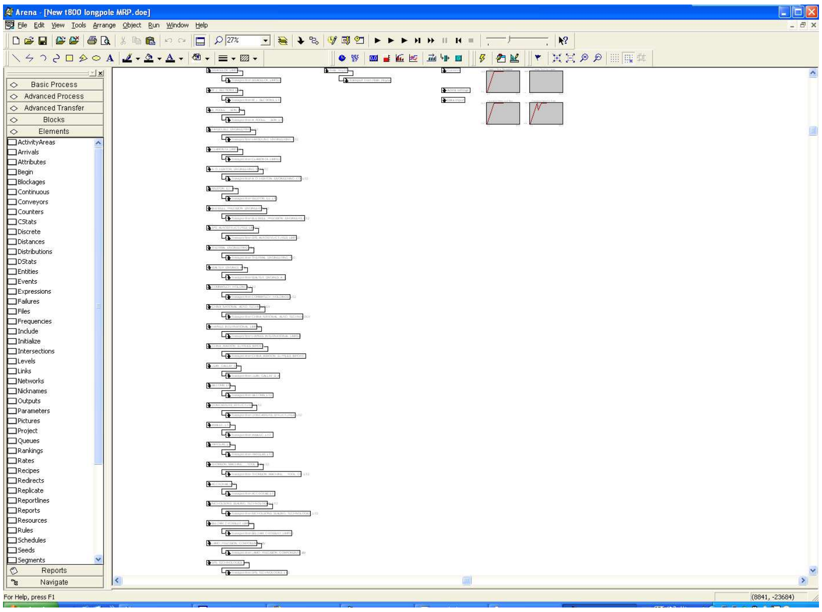


Figure 4.7 The finish M4800T004_71999 model

To run the Arena model successfully in my computer, the set of run speed are (this could be found by clicking the operation button under tool menu in Arena) :

Guided transporter matrix size:

ICXM= 300

Number of elements in parse array:

RVEC= 1100000

IVEC= 1100000

MVEC= 1100000

CVEC= 1800000

Number of elements in runtime array

Business School, the University of Nottingham

RSET= 30000000

CSET= 15000000

These sets are based on the computer which did this experiment.

The detail of the computer

- Data collection:

As is described in *SCMB User Manual* (Cao, 2005), the data output of SCMB is follow the performance evaluation system of the Supply Chain Performance Indicators associated with the SCOR (Supply Chain Operations Reference) model.

- Throughput (accumulative or per time period)
- Order Fulfillment Lead Time (from order receipt to customer delivery). The average order lead time can be calculated as

  Average lead time over chosen time period =

  Σ(Lead time of every order)/number of entities)

- Fill Rate by Order

  The average fill rate of orders can be calculated as

$$Average\_fill\_rate = \frac{\Sigma(Delivered\_quantity / Ordered\_quantity)}{Number\_of\_time\_periods} \times 100$$

- Tied up capital. It is calculated as

  Tied-up Capital = Standard Cost x WIP (work in product) + Standard Cost x Finished product Inventory

The M4800T004_71999 MRP model was running for 1080 days in simulation. As result, the throughput, lead time and tied-up capital are showed below. The order full fill rate is almost 0 and too little to be showed on the graph.

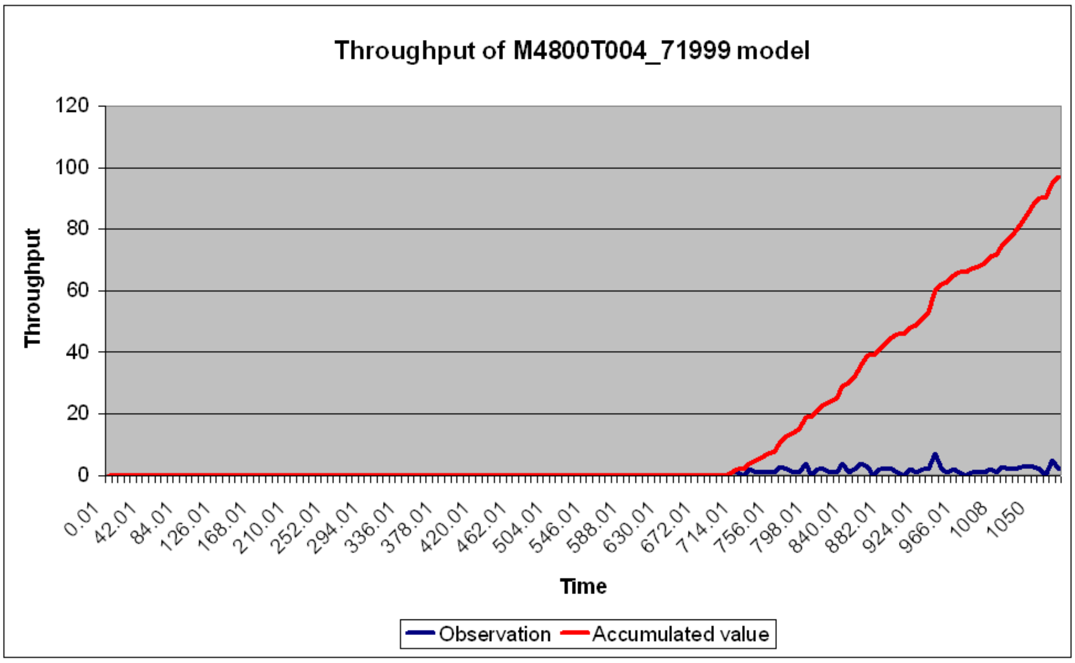


Figure 4.8 The throughput of M4800T004_71999 MRP model

From the graph of the throughput, totally 97 Trent 800 engines are delivered in 1080 days.

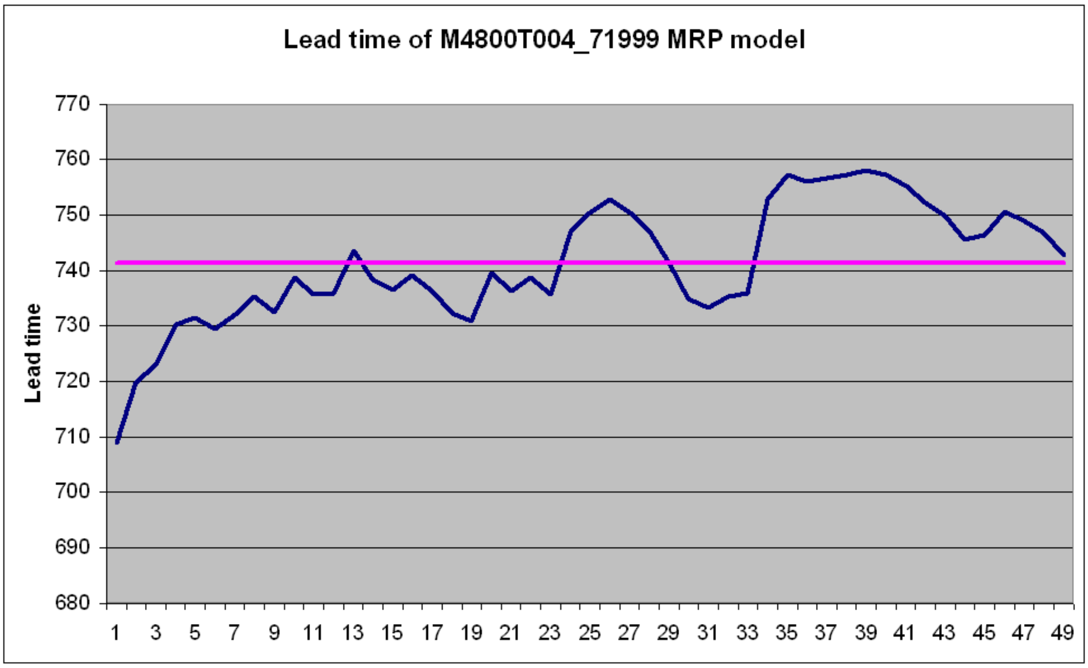


Figure 4.9 The customer order lead time of M4800T004_71999 MRP model

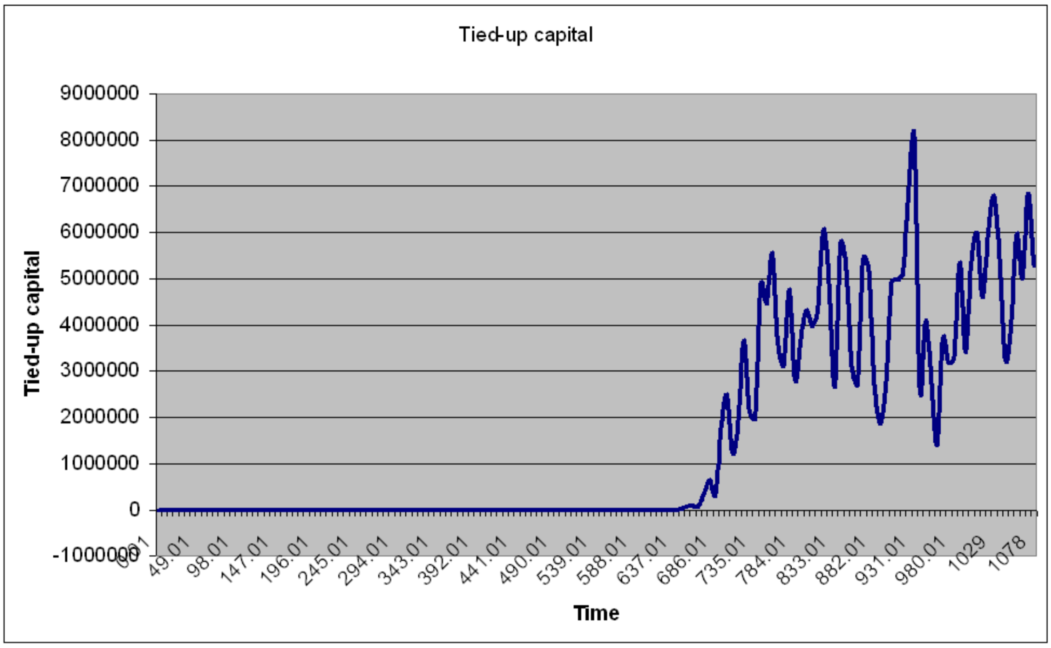


Figure 4.10 The tied-up capital of M4800T004_71999 MRP model

The average tied-up capital of M4800T004_71999 MRP model= ∑Tied-up capital/running time=217571.5238

The most important data, the average lead time is 741.27612 days. It means over 2 years. The tied-up capital keeps zero (warm up time) until 385 day. Then it waves between 2000000 and 8000000.

4.1.3 Pull (no inventory model) model of supply chain simulation

To build the Pull model of M4800T004_71999, the only difference is to select no inventory in "do simulation" interface. Because the operation without any inventory is the pure pull strategy's specific feature, it is not difficult to build a pull model by SCMB.

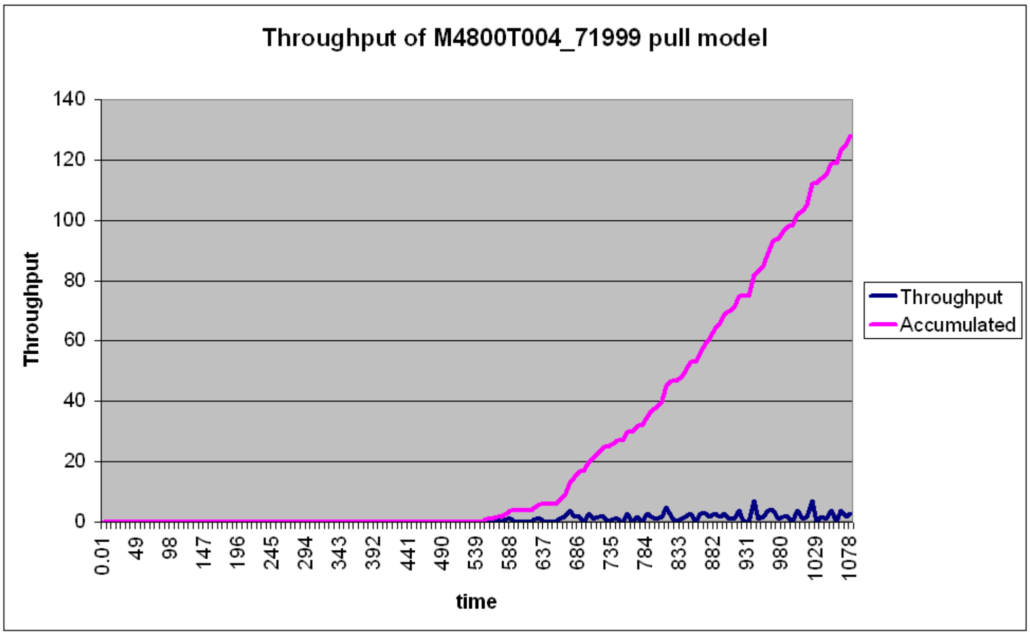


Figure 4.11 The throughput of M4800T004_71999 pull model

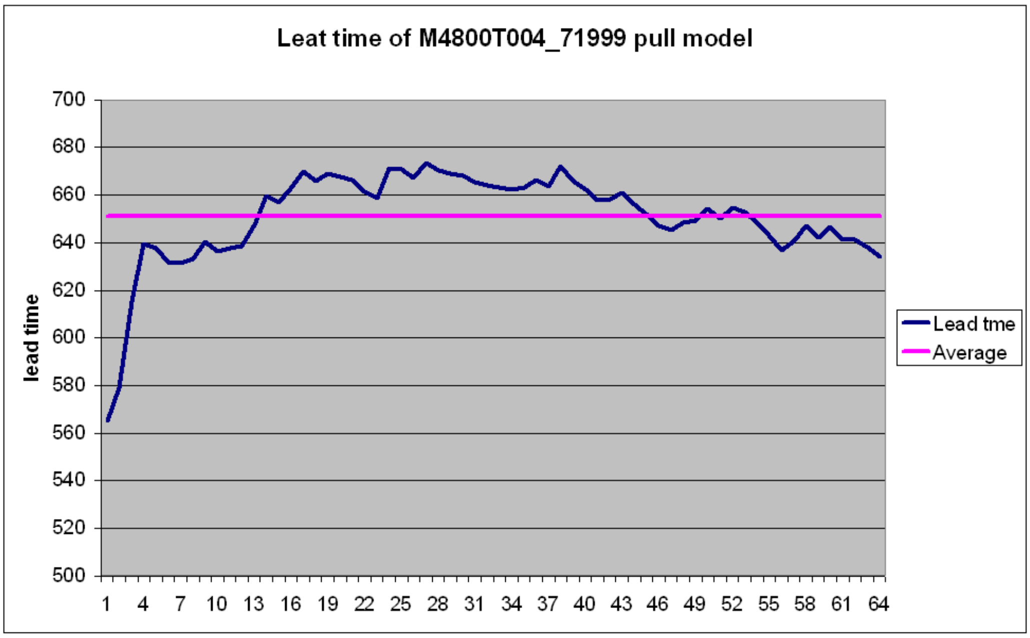


Figure 4.12 The customer order lead time of M4800T004_71999 pull model

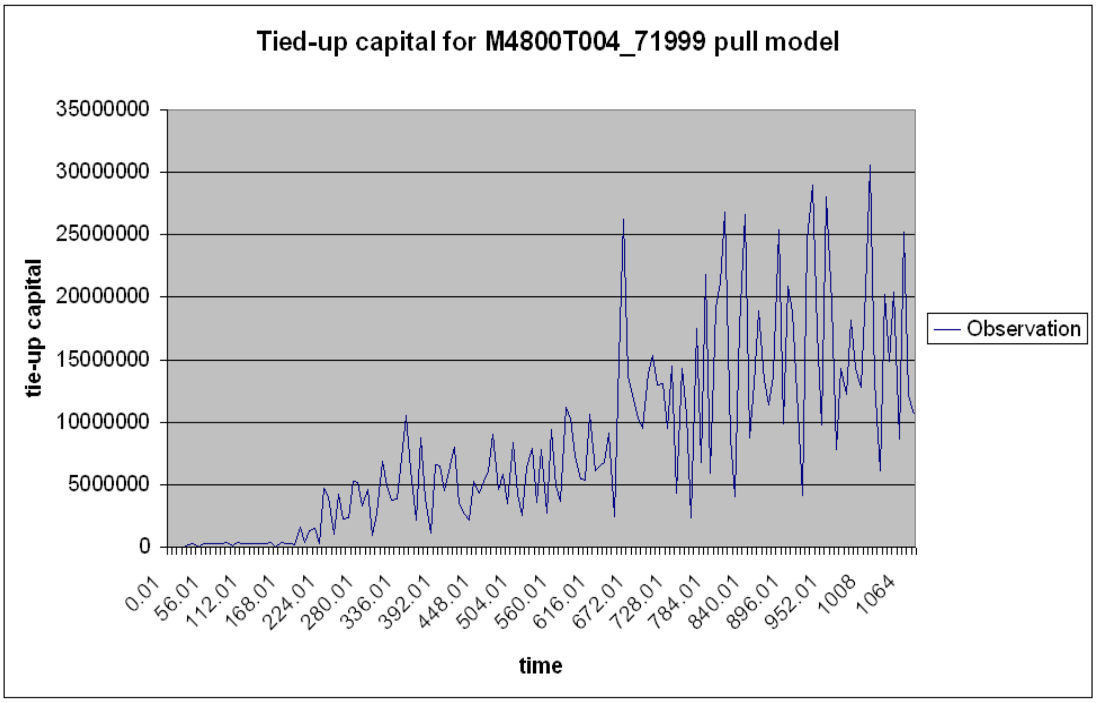


Figure 4.13 The tied-up capital of M4800T004_71999 pull model

The average tied-up capital is 1179448.

4.1.4 Primary analysis of MRP and pull model

- For tied-up capital:

Compared with the tied-up capital between MRP and pull model, the average of MRP model is almost twice of the pull model. The tied-up capital of MRP keep zero for 210 days, and increase significantly after 650 day. At the same time the pull model's tied-up capital waves from beginning to end, but the swing tends to become biggest with the time goes.

First of all, because the pull strategy does not hold any inventory in system, the inventory in system is much smaller than MRP model, it is reasonable keep a smaller tie-up capital in average. Secondly, the MRP ordered predict value at first of system runs, but pull only order material when order arrived. This conducts the tied-up capital wave at the beginning. With the order accumulated as time goes, the product in the system become more and more, the swing trends to serious. For MRP, because the demand is constant, the prediction could be more accuracy, so when operation starts, the tied-up capital keeps in a low value in a quite long time. But with the increasing of system run time, any small uncertainty could be accumulated to be a big influence to the inventory level. The tie-up capital increases significant at the end of operation period.

- For lead time

To find out the reason why the lead time is over 2 year, it should trace up to the original database and supply chain.

For both MRP model and Pull model, the values of initial inventory are 0. In pull strategy model, the lead time is the pure process time. And although MRP is operated by predict, there is no inventory at the beginning and its demand When do a pure pull, since the longest material lead time is about 650 days and there is no randomness with it, the product lead time are around 650 days. When using MRP, since materials are ordered based on their MRP time and their real lead time are always equal to or greater than MRP time. The MRP average product lead time is about 740 days.

More specifically, if the whole supply chain only orders one product, the lead time is still about 650 days, because the key process of this supply chain is about 650 days.

4.2 Discussion of several possible solutions

After the primary analysis of Trent 800 04 model supply chain from two kinds of operation method, MRP and pull strategy, it is almost impossible to shorter the process lead time. Because the 650 days is almost ten times of 65 days, even suppliers are from many companies in the world, it is too difficult to shorter all process at the same time. And the delivery time is also uncontrollable for Rolls-Royce. As a result, improve product process to decrease lead time is not tangible. All suggestion could only be taken out from the view of supply chain management direction. The solution could be considered from the following four directions.

4.2.1 For Push strategy

There is a possible solution method could be achieved in pure push strategy. In pure push strategy, the capacity of supply chain could be used efficiency to keep a large production rate. But at the same time, the bottle neck in supply chain could conduct high inventory cost and difficulty in control system.

With the target of lead time as 65 day, there is a possible solution by using pure push system. The solution could be processed with follow steps.

Reorganizing the supply chain within 65 days lead time, which means in each unit, the total lead time should be less or equal than 65 days. As the supply chain in figure 4.11, it could be divided into 7 units. In every unit, the process working time is 65 day per cycle. When the order centre get order from customers, the order center push 2 unit engine (the demand is constantly 2 per week). At the same time, all 7 unit push one work cycle forward (65 days).

As a result, the customer could get product from assemble line directly. Because the work cycle time in each unit is less or equal than 65 day, the customer order could be less than 65 days theoretically.

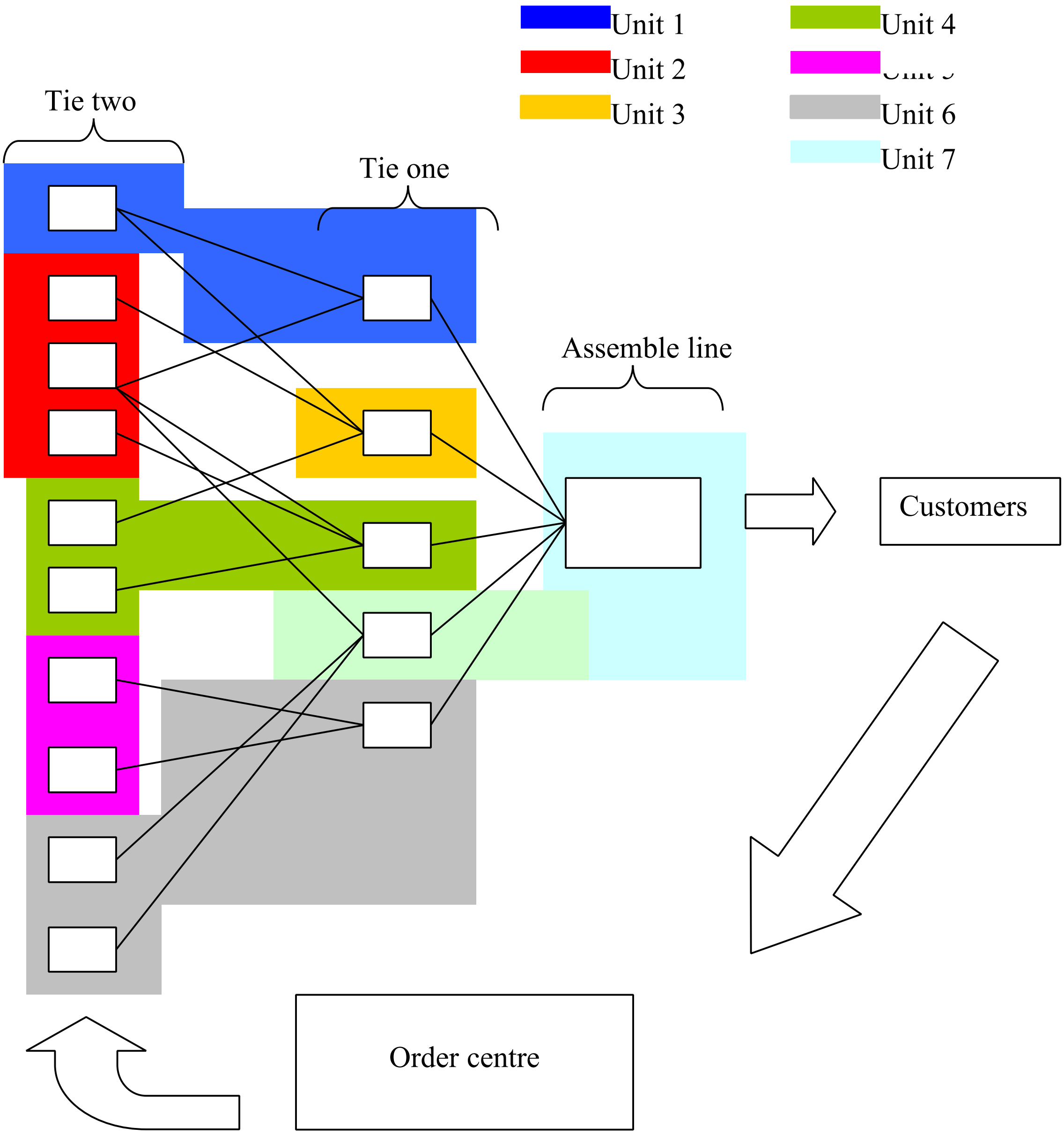


Figure 4.14 The imagination of pure push solution

- Advantage: this solution could keep a big productivity, because this is based on the pure push system. When the demand is stable, the produce cost could be very low.
- Disadvantage: when the demand fluctuates, the lead time could not be guaranteed to be less than 65 days. Because every unit keeps a inventory, the total inventory cost could be high.

- Tangible: first of all, from the observation of suppliers performance, there are only 87 supplier out of 265 could be performance less than 65 days. Others are more than 65 days. It means most supplier could not been united by this method. The longest performance time Secondly, the demand of 150 seater engine is still unpredictably, it is too risk to use this model without any demand predict. Finally, MRP is the main operation method in Rolls-Royce, it is difficulty and expensive to change to pure push strategy and other suppliers in supply chain may not change too.

4.2.2 For Pull strategy

Form the supplier performance, the longest lead time is 640 days, which is much bigger than 65 days.

So it is impossible to achieve lead time less than 65 days by pure pull strategy. The simulation of original Trent 800 04 model also proved this.

4.2.3 MRP + FPS (Finish part stock)

Except using pull or push strategy only, it is also possible to combine them together.

As the performance of MRP shown in original model, it is also impossible to decrease lead time to less than 65 days by pure MRP. Considered about this situation, the only thing could achieve the target of less than 65 days lead time is to build an inventory.

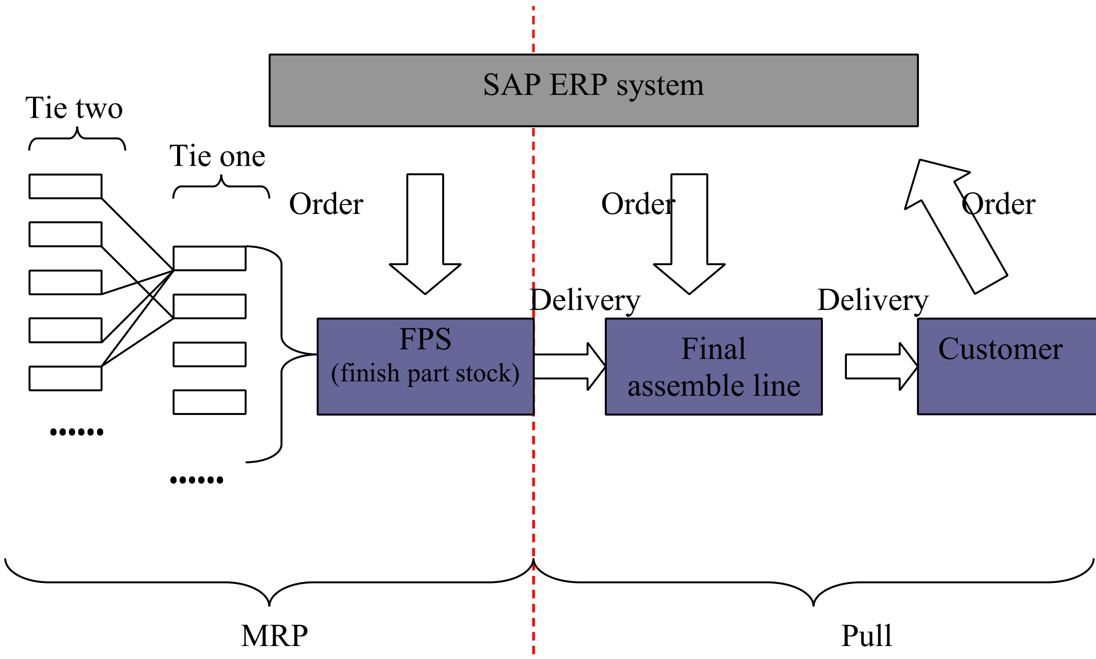


Figure 4.15 The structure MRP+ FPS (Finish part stock)

FPS (Finish parts stock) here are defined as the inventory one step before final assemble line, more specifically, it is the mixture inventory of eight components of Trent 800 04 model. As displayed on figure 4.15, idea of MRP+FPS is to add an inventory named FPS (Finish part stock) just before the final assemble line. This suggestion is link MRP to FPS, the MPR does not manufacture by the customer demand, but the FPS order. At the same time, the supply chain from final assemble line to customer are driven by pull strategy. All these activities are central controlled by SAP/ERP. The Customer order to SAP/ERP will be sent to final assemble line and FPS. FPS delivery material to final assembles line. Assemble line finish the order and delivery to customers.

- Advantage: The MRP and Pull could keep the inventory cost in an acceptable range and the inventory in the middle could achieve the lead time target at the same time.

- Disadvantage: Because of the FPS, the inventory cost could higher.
- Tangible: For Rolls-Royce, it is easy to accept by only add an inventory. In the supply chain database, the final assemble is only 11 days, much less than 65 days, so it is possible to meet the target.

4.2.4 MPR + Finish product inventory

MRP + Finish product inventory is similar to MRP+FPS. Both of them are mixed MRP and pull strategy. And they all use inventory to decrease lead time. The difference between them could be list blow.

- MRP + Finish product inventory get shorter lead time
- MRP+FPS is more flexible

In conclusion, both MRP+FPS and MRP + Finish product inventory are tangible plan for this research. The next step is put them into practice. After discussed with Dr Cao, the MRP+ finish product inventory is much easier to be operated by data-driven simulation. Through some program change of SCMB, an new model of MRP+ finish product inventory model is added. It will be experiment in next chapter.

Chapter five: supply chain reconstruction planning and simulation experiment

5.1 About MRP + finish product inventory model

As is discussed in Chapter four, the solution which is decided to put into experiment is MRP+ finish product inventory.

Figure 5.1 is the structure of MRP+ finish product inventory model.

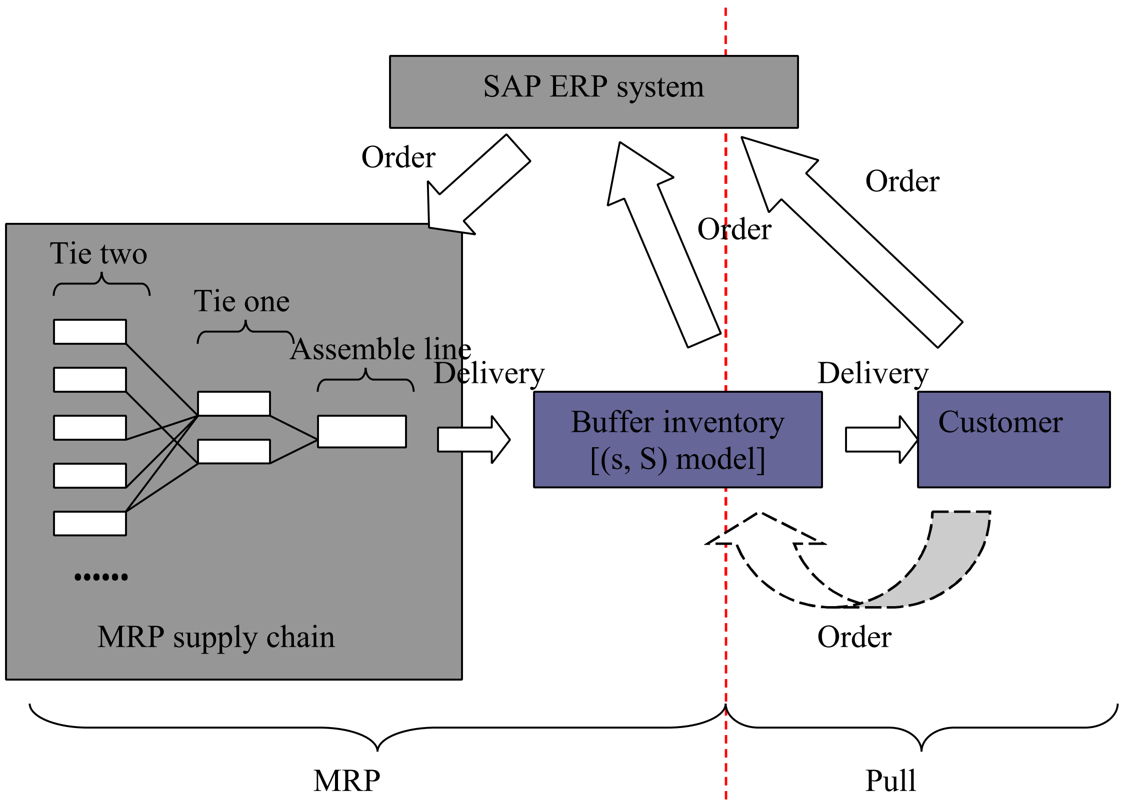


Figure 5.1 The structure MRP+ Finish product inventory

The MRP+ finish product inventory model is a supply chain mixed MRP and pull supply chain. The major difference to original Trent 800 04 model is the buffer inventory for finish product. In this supply chain, every process before buffer inventory is operated as MRP and supply chain after buffer inventory is in pull strategy. The whole supply chain is central controlled by SAP ERP system. The inventory could guarantee lead time less than 65 days when the MRP manufacture could keep an acceptable process cost.

One thing need to be noticed that the MRP is driven by the order of finish product inventory, but not customer order.

5.2 About inventory

To decrease lead time, inventory is the key of the whole supply chain model. Keeping too much inventory will increase lead time significantly, but holding not enough inventory level could not guarantee the lead time.

The Buffer inventory is using (s, S) model to control inventory level, which is one of the most popular inventory model. To achieve the lead time in a suitable amount, the s (the inventory holding position) should be enough for the 651 days (process lead time) demand level. Beside this, a safety stock is necessary to avoid risk. The formulation of "s" is:

s= the inventory for process lead time+ safety stock

The "S" could be a little more than "s" because if "S" is too high, warehouse will hold too much inventory.

Beside "s" and "S", to set experiment of MRP+ finish product inventory model, two data should be set, which are minimum order quantity and initial inventory.

To check weather MRP+ finish product inventory model is efficiency, the initial inventory is set the same as the volume of “s”. and the minimum order quantity should be a little more than the difference between “s” and “S”, because this could guarantee order could be filed efficiently.

Another thing need to be notice is the lead time in the result is still not the final lead time of the supply chain because the value of order time and delivery time is default to be zero.

Lead time in the reality= lead time in the simulation +order time +order delivery time

5.2 Experiment process and output

As is described before, the proceeds lead time is about 650days, and the demand is 2 per week, so:

Table 5.1 The setting of three expriment

Experiment No	Safety stock	s	S	min_order	initial inventory
1	little	190	200	15	190
2	10%	200	215	20	200
3	30%	240	260	25	240

As displayed in Table 5.1, three experiments are made for different safety stock volume.

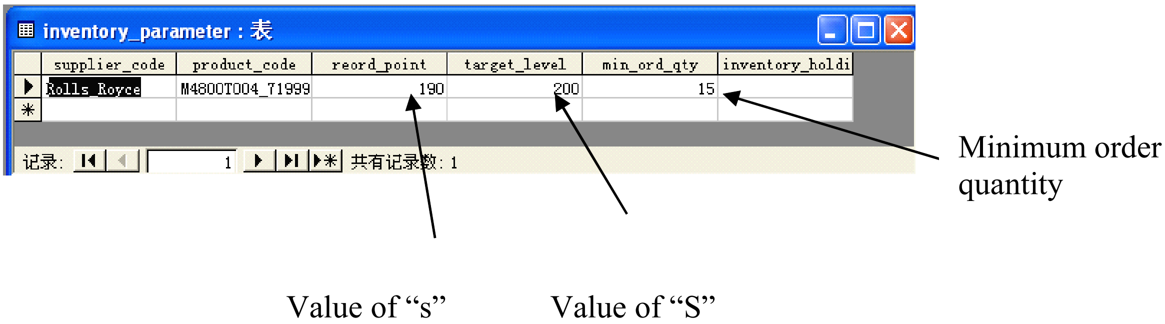


Figure 5.2 Experiment data set in Access Table

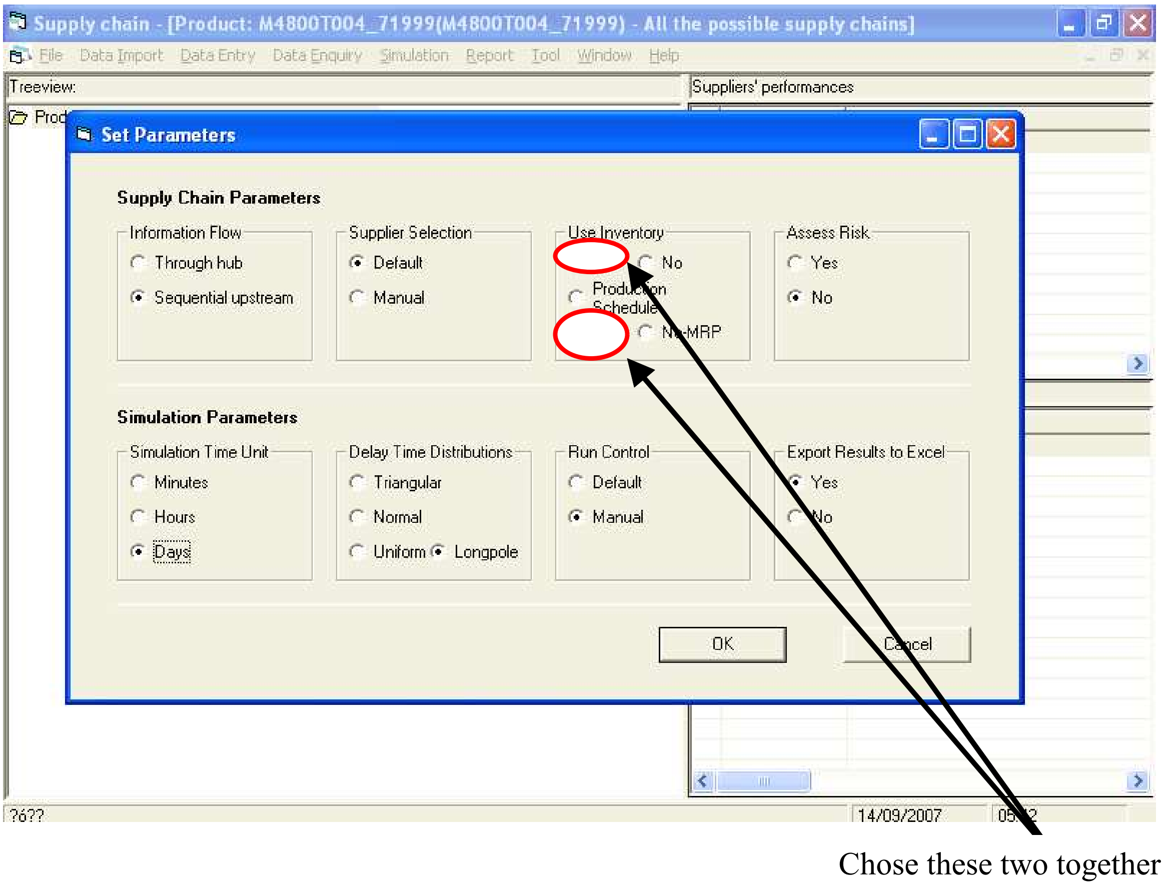


Figure 5.3 MRP+ finish product in SCMB

The result of Customer order lead time in three experiment

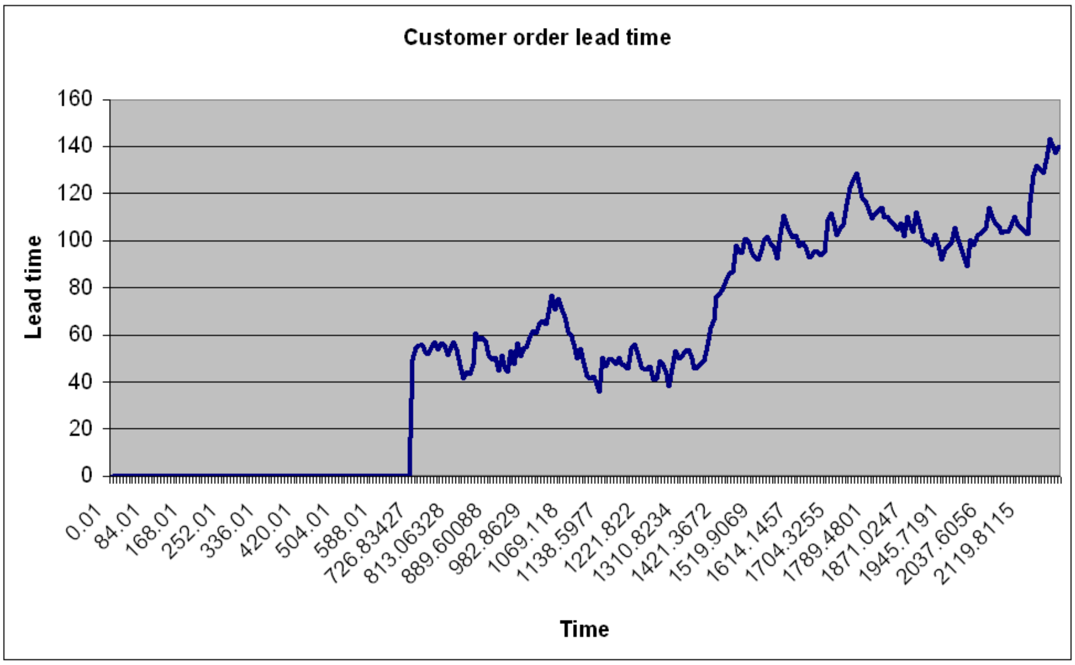


Figure 5.4 Customer order lead time of Experiment No.1

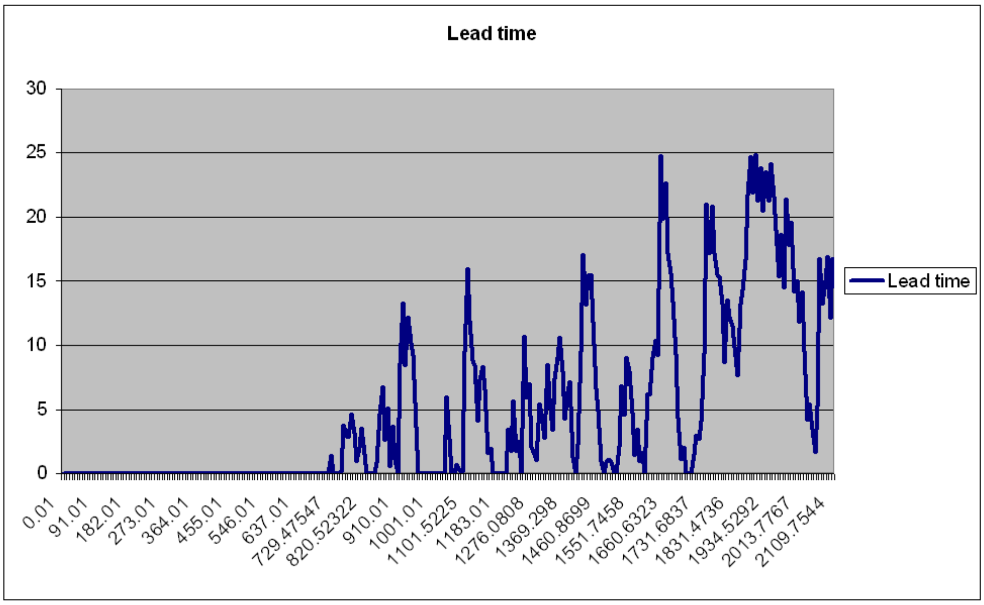


Figure 5.5 Customer order lead time of Experiment No.2

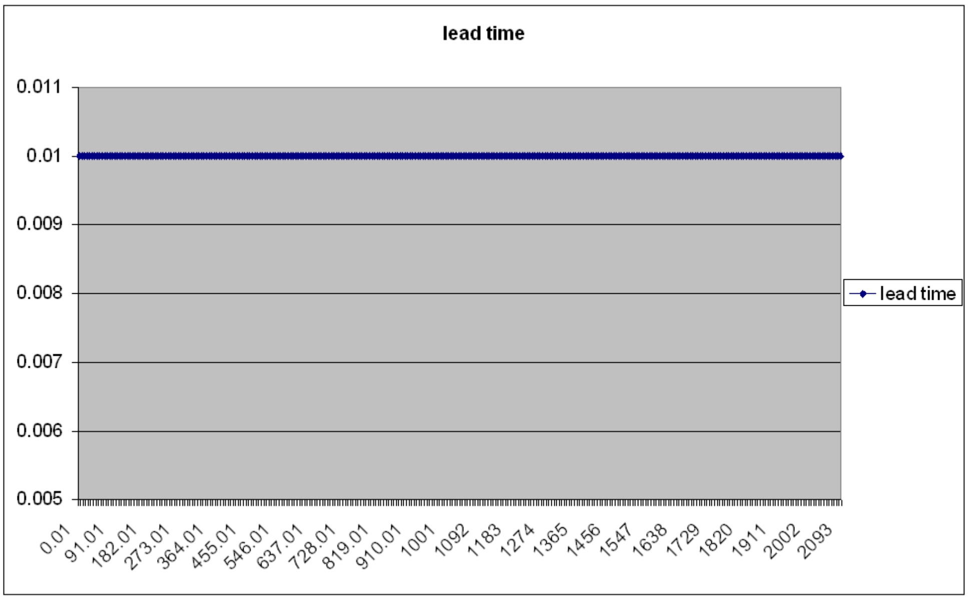


Figure 5.6 Customer order lead time of Experiment No.3

From the comparison lead time of three experiments, the No.1's lead time increased significantly after 726 days, and exclude 65 day after about 900 day. Obviously, the experiment is not fit the experiment requirement. The reason is Experiment No. 1 does not have enough safety stock for supply chain uncertainty. After a long period, the uncertainties accumulate to a big lead time issue and over 65 days. Although the lead time of Experiment No.2 is also fluctuant, but it never over 25 and the fluctuant trend is stable in a certain area. Because the inventory level is too high for current demand, the order could be filled immediately.

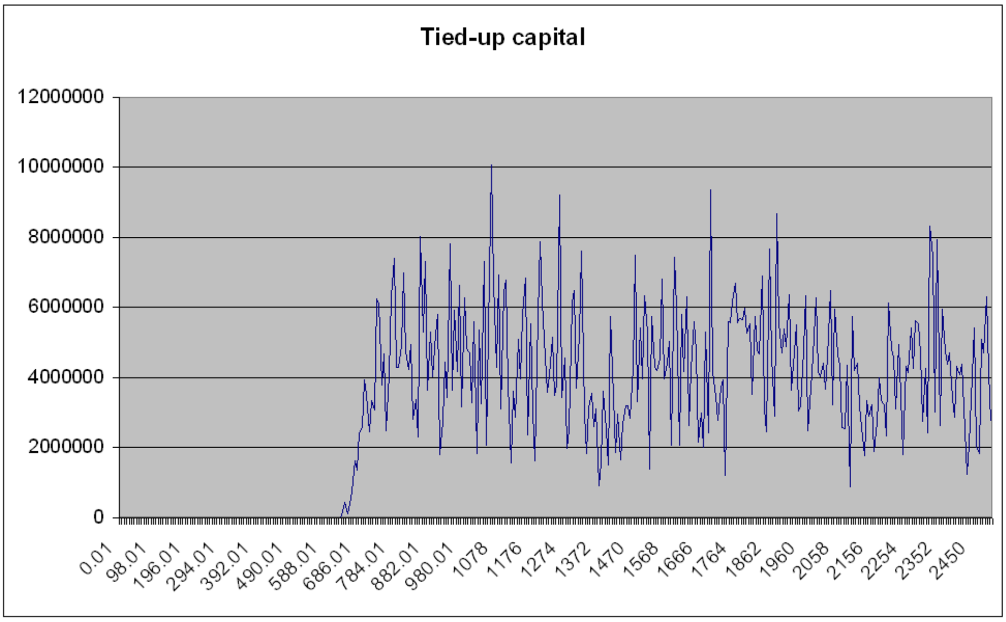


Figure 5.7 Tied-up capital of Experiment No.1

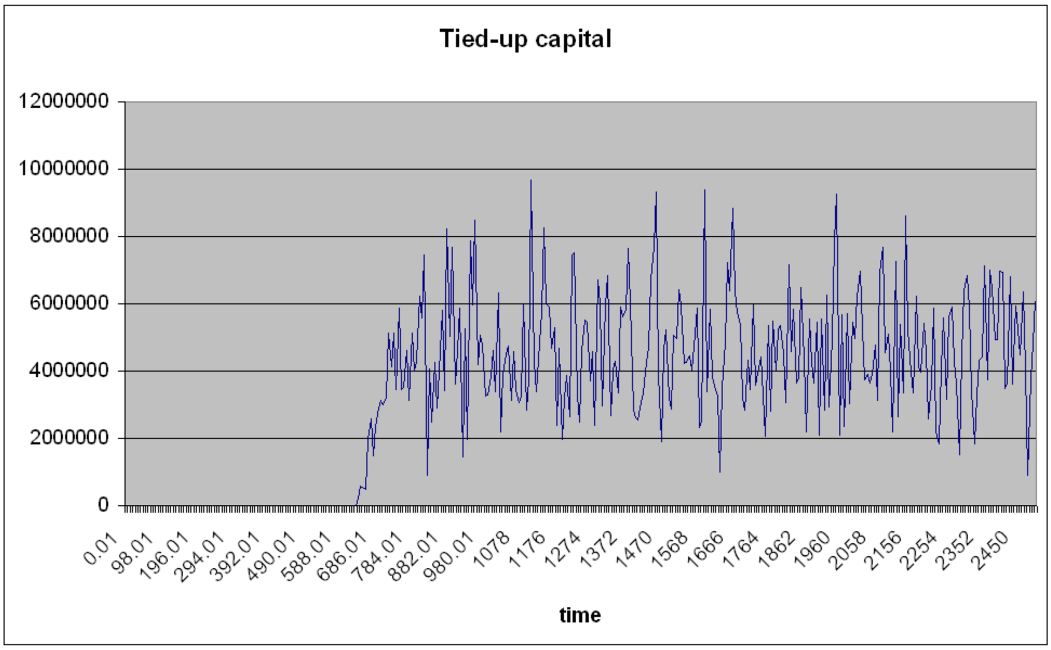


Figure 5.8 Tied-up capital of Experiment No.2

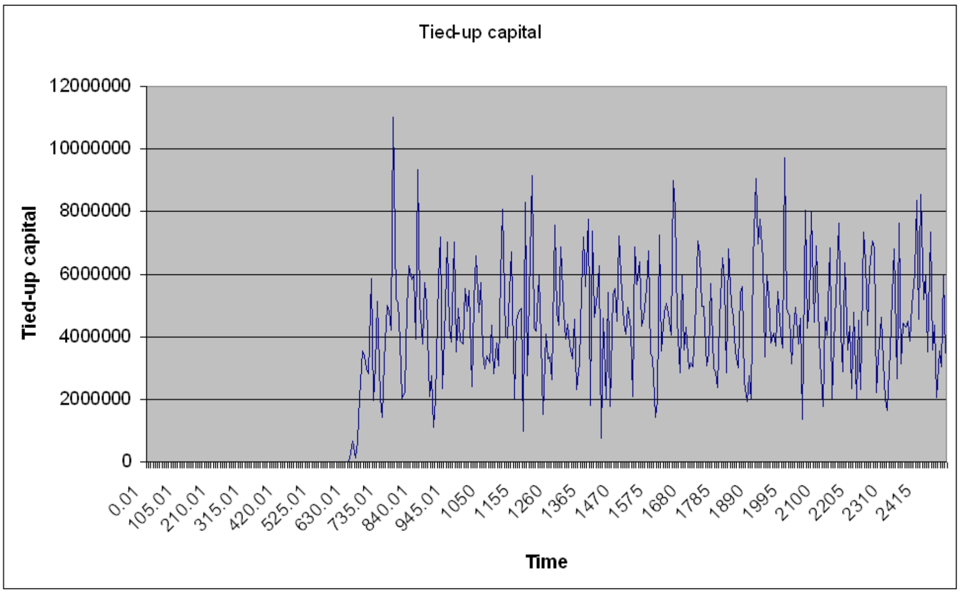


Figure 5.9 Tied-up capital of Experiment No.3

Although the tied-up capital of three experiment are similar, but the real cost should include the inventory holding cost, which is 190*unit hold cost for No.1, 200*unit hold cost for No.2, and 240*unit hold cost for No.3. So the No.2 experiment is the most economy inventory level for the inventory level.

As a result, the MRP+ finish product inventory could achieve the lead time target. And the economy inventory level approximate could be:

s= the inventory for process lead time+ safety stock= the inventory for process lead time*110%

5.3 The discussion in establishment of inventory

Because the running of MRP+ finish product inventory required the inventory filled at the beginning. An experiment about the building inventory is necessary. This time, the inventory is built on the assumption that no demand comes in firstly. To build a inventory level of s= the inventory for process lead time+ safety stock= the inventory for process lead time*110%, the output of experiment shows below.

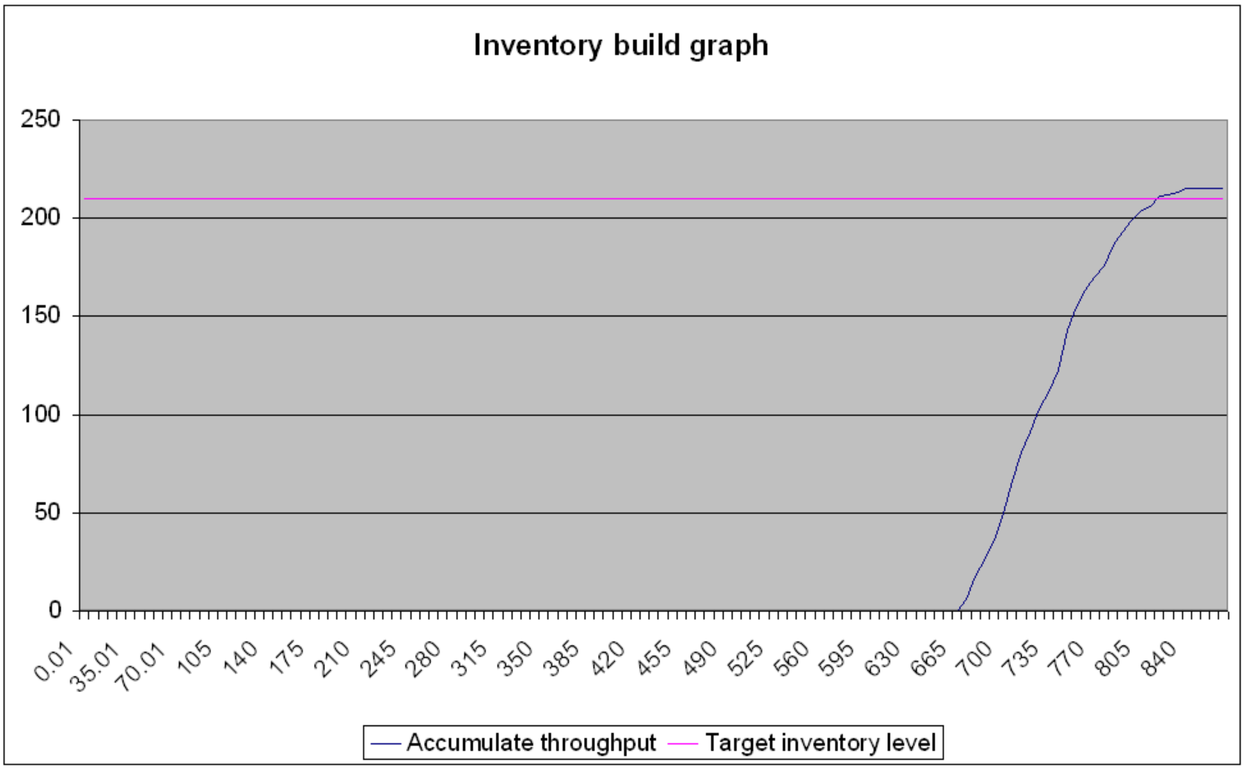


Figure 5.10 Inventory build graph

From figure 5.10, the inventory establishment needs 819 days, which is a quit long time to set up an inventory like this. To do nothing just building inventory for over 800 day is a big challenge for Rolls-Royce. Is it possible to build inventory a when fill customers' order?

This experiment could be designed for 2 unit demand per week and no initial inventory and (s, S) model for s=200,S=215. It simulates for 10 years.

From figure 5.11, it is impossible to build inventory when fill customer order, because the capacity of supply chain.

So for building the inventory, there are two method: one is building inventory but not accept any customer order for 800 days, the other method is increase capacity by find more suppliers.

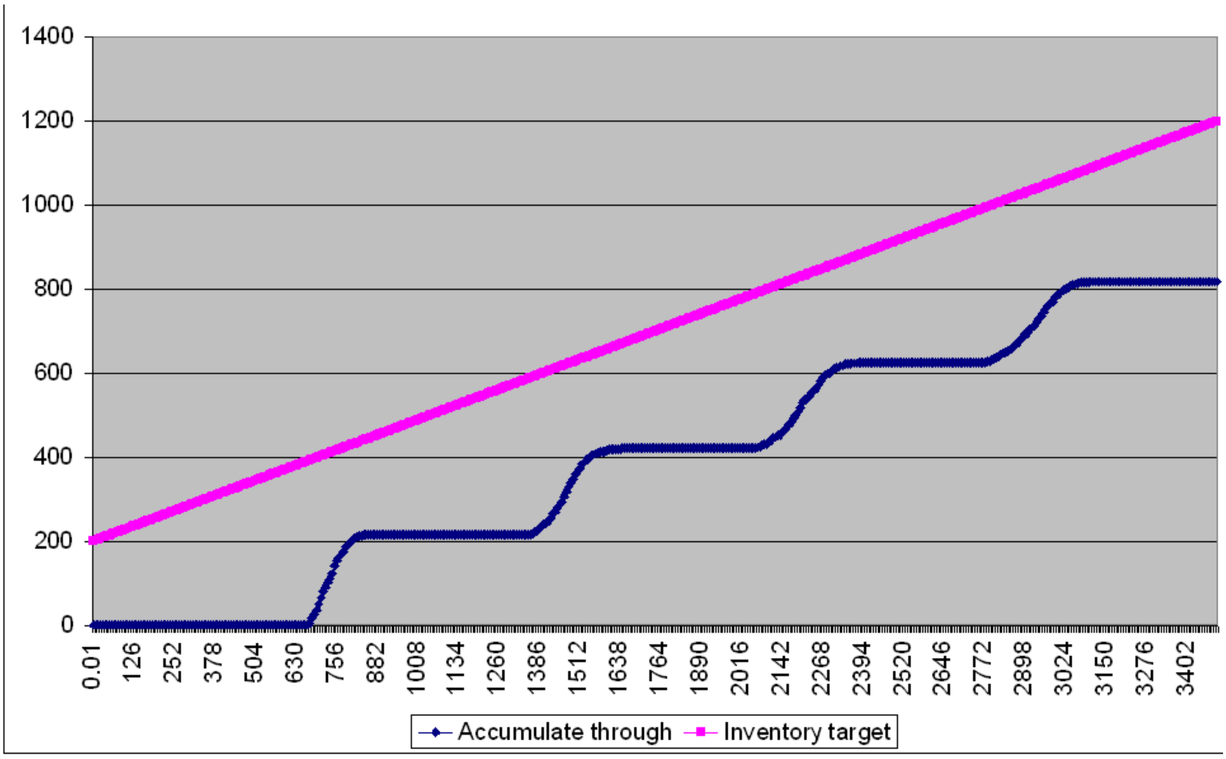


Figure 5.11 Inventory build with fill customer order

5.4 The discussion in fluctuating demand

To simulate fluctuating demand situation, an exponential level increasing demand is put into demand. The demand increase from third week and jump as 2, 4,8,16,31,64,128, then back to normal level. The lead time could graph is showed below:

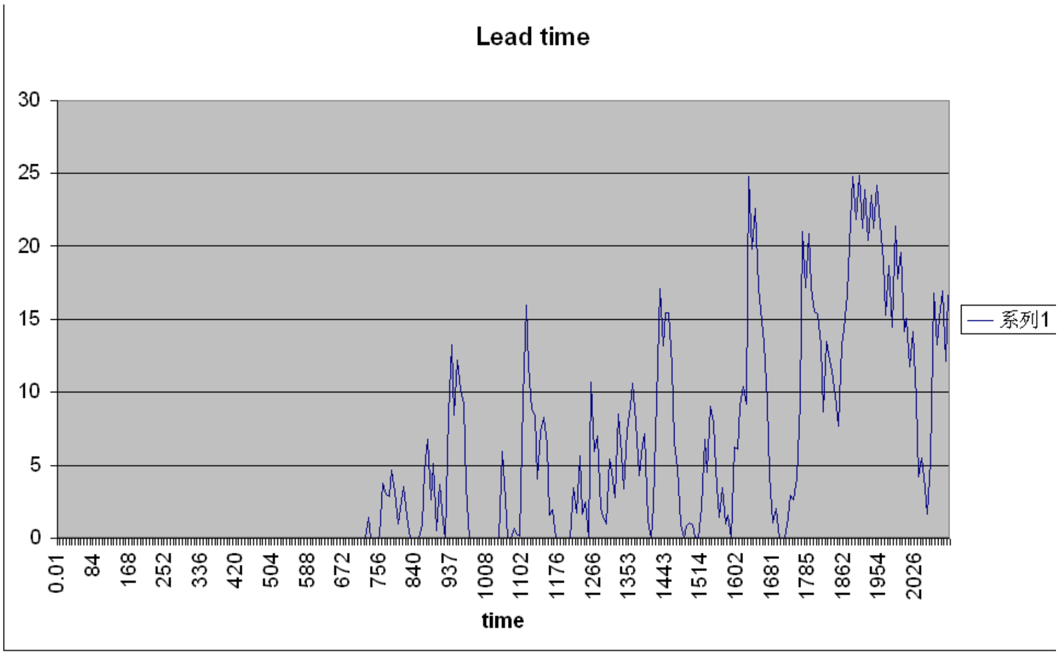


Figure 5.12 Lead time graph for a singe exponential increasing demand

Compared with the figure 5.5 , figure 5.11 does not change too much. Because the exist of large mount of inventory, the influence of fluctuating demand is limited in a certain degree. The way which demands fluctuating may damage lead time is the demand increased sharply over the inventory level or the demand is unstable for a very long time, but it is almost impossible.

5,5 Recommendation of MRP + finish product inventory

In conclusion, the MRP + finish product inventory could achieve the 65 lead time target with the help of already existed inventory. The inventory level of finish product inventory is about:

s= the inventory for process lead time+ safety stock= the inventory for process lead time*110%.

And inventory building is a serious issue for Rolls-Royce because of the capacity. To build the inventory, Rolls-Royce could only focus on inventory building for about 800 days or increasing capacity.

Chapter six: Conclusion and Recommendation

The lead time target of 65 days is really a serious challenge for Rolls-Royce. But it is not impossible.

In this article, the MRP+ finish product inventory has been experimented and been proved a tangible way to achieve 65 lead time inventory target.

Another method of MRP+FPS is also recommended, but because of the time and energy limited, it has not been experimented by data-driven simulation.

So, for the requirement of 65 days lead time, MRP+ finish product inventory is a tangible method which has been experimented. To make this model more practical, the finish product inventory model is (s,S), and s= the inventory for process lead time+ safety stock= the inventory for process lead time*110%. S could be only a little bigger than s. The other important condition is the initial inventory. But the difficult is on the inventory building method. The two way to possible inventory building way is build inventory for 800 day without any customer order filled, or improving the capacity of 150 seater engine supply chain by add more suppliers one critical path. The first way may loss a lot of customer orders; more simply, cost is very high. Judging from this point, increase supply chain capacity is more efficiency.

From the order throughput of Boeing 737, if the 150 seater engine performs the same as Boeing 737, the push strategy with supplier unit may be achievable. Although it looks impossible in data-driven simulation, fro a very high market demands, push strategy could keep the best capacity performance. If possible, the work unit could be mush smaller and inside the suppliers, the whole supply chain could works like one production line and every small unit's lead time is less than 65 days. Through push from raw marital. the 65 days lead time also could be possible. But it is also needs fill all production inventory first.

Generally, at the first glance, no matter MRP+ finish good inventory or MRP+FPS, the inventory is necessary. Although it looks cost a lot on inventory, but it wins customer orders, especially, 150 seats engine is a very seductive market which is bigger than any market Rolls-Royce has got. The large amount of potential benefit could make any impossible target possible, not to mention 65 days lead time has been proved tangible by data-driven simulation.

Within several months working on data-driven simulation, data-driven simulation has exhibited its fascination to me. The idea of using SAP ERP database is really a genius point in supply chain performance prediction. Data-driven simulation saved a lot time and money on supply chain research; moreover, it makes experiment for not existed supply chain possible. In the future, it could be used in much more broad area, such as quality management, manufacture planning, reserve logistic or even in the finical sector of view.

Even though, no matter how excellent data-driven simulation is, the knowledge and experience of supply chain management are still essential to success.

Reference

Bailor,C. 2006 For *CRM, ERP, and SCM, SAP Leads the Way*; New York: CRM.com available on:
http://www.destinationcrm.com/about/contact.asp [accessed on 25th August 2007]

Beamon, B.M., 1998. Supply chain design and analysis: models and methods. *International Journal of Production Economics* 55, 281-294

Boeing, 2006 *Boeing Facts*; USA: Boeing available on:
http://www.boeing.com/commercial/737family/pf/pf_facts.html [accessed on 25th August 2007]

Bolstorff, P. & Rosenbaum, R.G. 2003 *Supply Chain Excellence: A Handbook for Dramatic Improvement Using the SCOR model*; USA: Amacom

Bowersox, D.J. & Closs, D.J. 1996 *Logistical Management: The Integrated Supply Chain Process*; USA: McGraw-Hill Companies

Bryman, A.,1988 *Quantity and Quality in Social Science*; New York: Routledge. p 1. p 14 p 94

Cao, B., Tannock, J. & Kim, C. 2005 *Supply Chain Model Builder User Manua*; UK: VIVACE (confidentianl)

Chase, R. B., Jacobs, F. R., Aquilano, N.J. *Operations Management for Competitive Advantage*; London: McGraw-Hill

Chopra, S. & Meindl, P. 2004 Supply *Chain Management: strategy, planning, and operations*; USA: Pearson Education, Inc p5

Cooper, M., Lambert, D., Pagh, J., 1998 Supply Chain Management: More than a new name for logistics, *International Journal of Logistics Management* 8/1, S, 1-14

Cordier, F. & Magnenat-Thalmann, N. 2004 *A Data-driven Approach for Real-time Clothes Simulation*; Swiss: University of Geneva available on :
http://www.miralab.unige.ch/papers/359.pdf [accessed on 25th August 2007]

Dadley-Web, J. 2007 *Understating Rolls-Royce's Supply Chains through the Development and Use of a Data Driven Simulation Tool*; Southampton: University of Southampton

Forrester, J.W. 1961 *Industrial Dynamic*; New York: London

Forrester, J.W. 1958 Industrial dynamic: A major breakthrough for decision makers, *Harvard Business Review*, Vol. 36 July-August 37-66

Hahmias, S., (2005) *Production and Operation Analysis*, 5st ed ; Publisher: McGraw-Hill

Handfield, R.B., Nichols, E.L., 2002 *Supply Chain Redesign: Transforming Supply Chains Into Integrated Value Systems*, USA: Finical Time Prentice Hall

Harrison, T.P., Lee, H.L., Neale, J.J., 2005 *The Practice of Supply Chain Management: Where Theory and Application Converge*; USA: Springer Science& Business Media p372

Hartmann S., 1996 The World as a Process: Simulations in the Natural and Social Sciences, in: R. Hegselmann et al. (eds.), *Modelling and Simulation in the Social Sciences from the Philosophy of Science Point of View*, Theory and Decision Library. Dordrecht: Kluwer 1996, 77-100.

Hayden, R. Wheeler, M. and Schultz, C. *2007 Turbo-Charge Your SAP Supply Chain with Voice*; sponsored by Voxware, Motorola, and PEAK Technologies available on: **http://www.bitpipe.com/data/web/bpmd/bpmd_details.jsp?resId=1187116155_696&psrc=DPRLT** [assessed on 30 August 2007]

Jaffe, D.T., Scott, C.D., 1989 *Managing Personal Change*; USA: Crisp Publication p71

Jacques, V. 2006 *International outsourcing strategy and competitiveness*; Paris: Editions

Kapuscinki, R., 2004 *Inventory Decision in Dell's Supply Chain*; Publisher: Informs

Kelton, W.D., Sadowski, R.P. & Sturrock, D. T. 2003 *Simulation with ARENA*; Singapore: McGraw-Hill

Kennedy,C. Theodoropoulos, G. 2005 *Towards Intelligent Data-Driven Simulation for Policy Decision Support in the Social Services*; Birmingham: University of Birmingham available on: http://www.ncess.ac.uk/research/sgp/aimss/20051001_kennedy_PolicyDecisionSupport.pdf [accessed on 25th August 2007]

Business School, the University of Nottingham

Lee, H. L, Padmanabhan, V. & Whang, Seungjin 1997. The Bullwhip Effect in Supply Chains. *Sloan Management Review* /spring 38 (3): 93-102.

Lewis, M. & Slack, N. 2003 *Operations Management: Critical Perspectives on Business and Management;* London: Routledge

Lysons, K., Farrington, B., 2006 *Purchasing and Supply Chain Management*; USA: Pearson Education

Madu, C.N. & Kue,C. 2004 *ERP And Supply Chain Management*; Fairfield: Chi

Pugh, P. 2002 The *Magic of a Name: The Rolls-Royce Story Part 3 A Family of Engines*; Cambridge: Icon Books

Remenyi, D., 1998. *Doing research in business and management : an introduction to process and method***;** London: Sage

Rolls-Royce 2006 *Trent 800:Power for the Boeing 777*; UK: Rolls-Royce available on:

http://www.rolls-royce.com/civil_aerospace/downloads/airlines/trent_800.pdf [accessed on 25th August 2007]

Simchi-Levi, D, & Kaminsky, P. 2004 *Managing the Supply Chain: The Definitive Guide for the Business Professional*; USA: McGraw-Hill

South, R., 1697. A Sermon Delivered at Christ-Church, Oxon., Before the University, Octob. 14. 1688: Prov. XII.22 Lying Lips are abomination to the Lord, pp.519–657 in South, R., *Twelve Sermons Preached Upon Several Occasions (Second Edition);*, London: S.D. for Thomas Bennet, Volume I,

Stadtler & Kilger 2005 *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies*; Berlin: Springer Berlin

Tannock, J., et al., Date-driven simulation of the supply-chain—Insights from the aerospace sector, *International Journal of Production Economics* (2007), doi:10.1010/j.ijpe.2007.02.018

Tannock, J.,et al., 2007 Data-driven Simulaiton of the Supply-chain: Insights from the Aerospace sector, *International Journal of Production Economics* 2007.02.018

Tannock, J. & Kim, C. *Modelling the Supply Chain*; UK: VIVACE (confidentianl)

Vollmann, T.E. 2005 *Manufacturing Planning And Control Systems for Supply Chain Management* : USA: USA: Pearson Education

Waldner, J. 1992. *Principles of Computer Integrated Manufacturing*; UK: Wiley

webMethods, 2005 *webMethods for SAP: beyond SAP Business Connector 4.7*; USA:webMethods available on: http://www1.webmethods.com/PDF/webMethods_for_SAP-wp.pdf [accessed on 25th August 2007]

Zillmann, D.,Bryant, J., 1982, *Selective Exposure to Communication*, New Jersey: Lawrence Erlbaum Associates p240

Appendix I

Non-Disclosure Agreement

This Agreement R-R/NDA NUBS/MBA is made this 20th day of June 2007
Between ;

ROLLS-ROYCE plc of 65, Buckingham Gate, London, SW1E 6AT,
and
of Shuaijie Shi

It is contemplated that certain technical and commercial information will be exchanged between the parties hereto (the "Participating Parties") relating to or in the context of the subject defined in the Appendix hereto. Each of our companies wishes to protect our respective interests in relation to this information whether such information is disclosed orally or in the form of drawings or written material or otherwise and to this end therefore the Parties herby agree to the following;

1. In respect of all information in whatever form acquired prior to or during the period of this Agreement by one Participating Party (the "Recipient Party") from any other Participating Party (the "Supplying Party"), relating to the subject defined in the appendix hereto (the "Information"), the Recipient Party hereby undertakes:-

    A. only to use the Information for evaluating or for preparing a quotation in respect of and/or evaluating the subject defined in the Appendix hereto, or for carrying out work for or with the Participating Party;

    B. only to disclose the Information and then only to the extent necessary to those of its employees to whom disclosure is necessary for the purposes specified in paragraph 1.A above. Reference to employees in this Clause 1B means employees of the Rolls-Royce group of Companies including but not limited to its subsidiaries and affiliates.

    C. not to disclose the Information to any third party or the fact that information is being exchanged with the Supplying Party except as provided in paragraph 1.B above, or as may be expressly authorised in writing by the Supplying Party,

    D. not to copy or reduce the Information to writing or store in any computer readable form, except as may be reasonably necessary for the purposes specified in paragraph 1.A above,

E. to return to the Supplying Party on demand all Information which has been supplied to or acquired by the Receiving Party in the form of drawings or written material or other recorded form including all copies thereof, and to delete all information stored in computer readable form,

and the Recipient Party will be responsible for the fulfilment of the above obligations on the part of its employees.

2. Paragraph 1. above will not apply to any Information which :-

A. is in or comes into the public domain otherwise than by a breach of these conditions, or

B. the Recipient Party had in its possession without restriction on disclosure prior to receipt from the Supplying Party, or

C. the Recipient Party lawfully receives from a bona fide third party without restriction on disclosure.

3. It is understood and agreed by the Participating Parties that for the purposes of this Agreement any Participating Party may disclose any Information received from one or more other Participating Parties to any of the other Participating Parties and that such Recipient Party shall adhere to the terms of this Agreement as if it were the Recipient Party and the Party originally disclosing the information were the Supplying Party.

4. Information shall be subject to the conditions as to (inter-alia) non-disclosure and non-use as set out above unless and until such time as the Information comes into the public domain otherwise than by breach of this Agreement or the Information is received from a bona fide third party as specified in sub-paragraph 2.C above. Upon the expiration of such period the said conditions shall cease to apply to such Information to the extent consistent with paragraph 5 below. The NDA will limited to the scope of the individual project and time. Given the sensitivities, the time element must be extended to 31 December 2008.

5. This Agreement shall not be construed as granting expressly or impliedly during the period specified in paragraph 4 above or thereafter any rights in respect of any patent, copyright or other intellectual property right belonging to the Supplying Party except to the extent necessary for the purposes specified in paragraph 1.A above.

6. The parties hereto shall perform their respective obligations hereunder without charge to the others.

7. This Agreement shall be governed by and interpreted in accordance with the laws of England.

IN WITNESS whereof the parties hereto have caused this Agreement to be executed by their authorised officers on the date first above written.

For and on behalf of
ROLLS-ROYCE plc

Shuaijie Shi ....
(Signature)

SHUAIJIE SHI ....
(Print Name)

MSc INTERN ....
(Position)

FOR RR

For and on behalf of

....
(Signature)

J G BADLEY-WEBB ....
(Print Name)

GPL ....
(Position)